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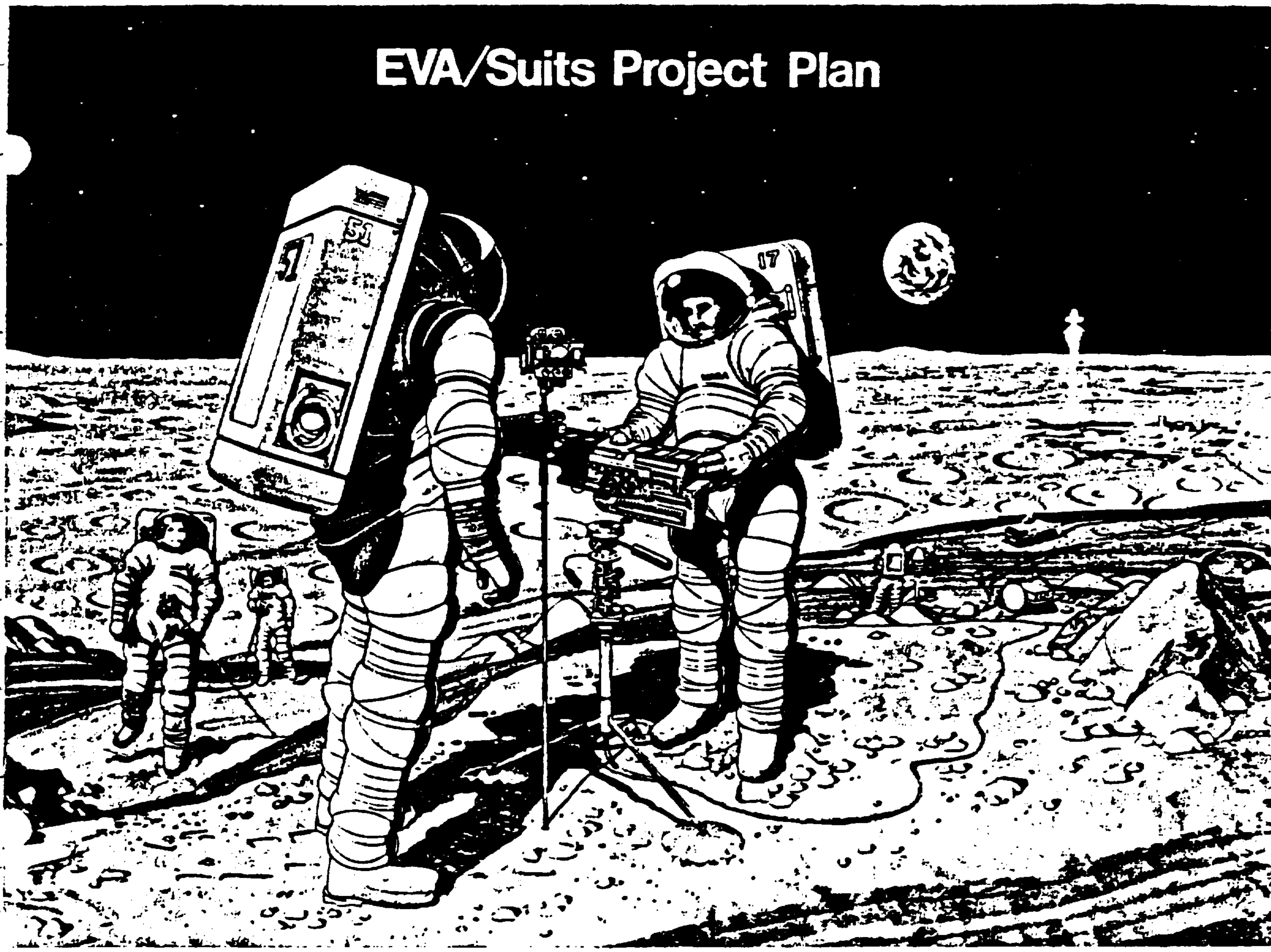
PROJECT PATHFINDER

EVA/SUIT PROJECT PLAN

Fall 1988

Office of Aeronautics and
Space Technology

National Aeronautics and
Space Administration
Washington, D.C. 20546



EVA/SUIT PROJECT PLAN

1 October 1988

PROJECT PATHFINDER

NASA
Ames Research Center

ACKNOWLEDGEMENT:

This document was produced by Ames Research Center in its role as the Pathfinder EVA/Suit lead Center. This final plan is the result of a collaborative planning effort involving the Office of Aeronautics and Space Technology Program Managers, Ames Research Center, Johnson Space Center, and Langley Research Center.

EVA/Suit Project Plan

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1.0 INTRODUCTION

Under the bold Pathfinder Project, NASA plans to develop technologies that will enable the U.S. Space Program to venture beyond the low earth orbit of Space Station. NASA is currently studying a broad range of potential missions, focusing on manned missions to Mars or to a Lunar base.

The Extravehicular Activity (EVA)/Suit element of Pathfinder encompasses a wide range of disciplines, from physiology to engineering to artificial intelligence. The intent of the EVA/Suit Project is to develop the technologies necessary to perform EVAs productively and efficiently during the proposed long-duration missions. It includes the design, fabrication, and test of concepts for pressure suits, portable life support systems, and ancillary equipment such as task displays, tools, and translation/transportation means. The selection and development of the actual flight hardware systems are not within the scope of Project Pathfinder.

Ames Research Center has been designated by the NASA-Headquarters Office of Aeronautics and Space Technology (OAST), Information Sciences and Human Factors Division, to be the lead center for the EVA/Suit Project element. This plan was produced by a team of Ames Research Center staff in collaboration with NASA-HQ, the Johnson Space Center, and Langley Research Center.

1.1 OBJECTIVES OF THIS DOCUMENT

This document is intended to provide an Agency-wide project plan for EVA technologies. It is the product of a series of meetings and workshops involving Headquarters and all participating centers, conducted over a three month period between April and June 1988. The full development and successful implementation of the plan will require the expertise, considerations, and input from representatives of all NASA field centers that will participate in future EVA technology development, including Ames Research Center (ARC), Johnson Space Center (JSC), and Langley Research Center (LaRC).

The objectives of the plan are twofold: 1) to relate the history and development to date of specific technologies so as to understand the rationale behind the proposed project thrust, and 2) to define the process by which NASA will develop these technologies in the future to support human presence beyond the Earth into the Solar System.

1.2 PROJECT PATHFINDER OVERVIEW

Under Project Pathfinder, critical technology options will be developed by OAST (Code R) and validated for a range of possible future solar system exploration missions. A decision on which of these possible missions to pursue will be made in the early 1990's, based on OAST technology developments and on the results of scenario studies conducted by OEXP (Code Z). Pathfinder will draw on the capabilities of industry, academia and government agencies, and cooperation among all three, to accomplish this goal in support of U.S. civil space technology leadership.

The five technologies to be developed under Pathfinder are described below.

- *Exploration Technology* includes all elements of autonomous exploration as technology demonstrators and precursors to manned exploration.
- *Operations Technology* includes all anticipated planetary surface operations.
- *Humans-in-Space Technology* includes all technology necessary to permit humans to travel to and live and work productively in the hostile environments of the moon and Mars.
- *Transfer Vehicle Technology* addresses the design of space vehicle systems.
- *Mission Studies* addresses the degree of systems autonomy, robotics, and the human interface to autonomous systems.

During the second five years of the project, prototypes of developed technologies will be fabricated and tested. The prototype subsystems will be integrated and undergo systems testing and evaluation in light of mission objectives. The 10-year Pathfinder effort will enable the timely development and qualification of flight hardware for a long-duration mission in the first five years of the 21st century.

1.3 MISSION STUDIES AND TECHNOLOGY REQUIREMENTS

In the early phase of the EVA/Suit element of the Pathfinder Project, technical efforts will focus upon requirements definition — specifically, mission requirements and biomedical/ physiological requirements. In these two areas, several tasks (described in Section 2.4) have been proposed for research in FY89. However, funding levels are not sufficient to address all requirements immediately. Listed herein are specific topics for which inadequate information is currently available. In order to begin a focused project, further research is needed in some key areas to converge on specific definitions and derive requirements. Because these requirements will be interpreted as design guidelines by EVA hardware and software engineers, timely consideration is imperative to the Pathfinder Project schedule.

Specific study topics which should be addressed by Code Z as part of their scenario studies are:

- mobility aids definition and requirements
- communication interfaces and requirements
- navigation requirements
- robotic system interface requirements

The definition of mission thermal environments and environmental hazards will be the product of FY90 tasks conducted as part of this project.

Topics to be addressed by the Code EB part of this project are:

- CO_2 partial pressure
- biomedical monitoring requirements
- fatigue/metabolic cost of EVA
- cleaning and decontamination requirements

1.4 TECHNOLOGY ASSESSMENT

There is a clear requirement for a manned presence at an EVA worksite, either to perform, observe, or supervise the actual tasks. The state-of-the-art of robotic devices is far from the point where an adaptive, autonomous machine can be considered as a means to perform a new, complex task without human supervision. However, current technology for manned EVA systems imposes serious operational and logistical constraints, limits EVA productivity, and cannot evolve to meet advanced mission requirements. As a result, EVA is often perceived to be an inefficient and dangerous means to accomplish mission tasks and is not considered to be a routine resource for use by mission planners. However, the EVA environment is relatively benign and safe compared to many environments on Earth in which people have worked routinely for years. For example, commercial divers routinely work in cold water with zero visibility and strong currents while saturated with exotic breathing gases at pressures of 30 atmospheres. The appropriate ensemble of EVA equipment must be developed to allow routine work in various future mission environments since direct, manual accomplishment is often the most cost-effective means to accomplish a wide variety of required tasks. Studies must be performed to identify the most appropriate portable life support system (PLSS) concept (i.e. highly compact but fully expendable vs somewhat larger but fully regenerable) for various mission scenarios.

Current EVA systems and technology have a number of limitations that make them unable to meet future mission requirements. Pressure suits operate at low pressure relative to the habitat pressure resulting in a significant bends risk even after extensive pre-breathing. Glove technology currently limits productivity due to fatigue, discomfort, and limited dexterity and tactility. Life support systems have prohibitive logistical support and maintenance requirements for use on extended missions. Therefore, advanced technology is needed in each of these areas to provide EVA systems for future missions.

The existing R&T programs have produced prototypes such as the AX-5 and ZPS MK III high pressure suits, prototype gloves, and end-effectors. The human anthropomorphic requirements for the pressure suit itself are reasonably well understood, but this is not the case for the glove. An obvious goal would be to provide bare hand capabilities, but since this is not achievable even with surgical gloves, a serious question remains: Provided that acceptable comfort and fatigue levels are achieved, what degree of dexterity and tactility is mandatory to meet the task requirements? Advanced materials and mobility joints will be necessary to provide durable and highly mobile suits and gloves. Various advanced, regenerable life support subsystems have been developed to the state of breadboard demonstration units. However, even optimistic projections of the ultimate size of flight versions show that a significant, and for some missions unacceptable, weight and volume penalty will be required to provide a regenerable system which will reduce the overall mission resupply requirements. Research is needed in all areas of portable life support technology to develop simple, reliable, fully regenerable subsystems that can be packaged into an easily maintained micro-climate control system comparable in size to the fully expendable systems currently in use. System size and weight will be even more critical for Lunar and Mars missions with surface gravities on the order of 1/6- and 1/3-g.

Other aspects of the required EVA work system are completely undeveloped even as concepts. For example, moving about on the near zero-g surface of a Martian moon may be more like mountaineering than walking. Requirements and concepts for the necessary EVA ancillary equipment for such scenarios have never been seriously considered.

For any mission scenario, advanced pressure suits must be developed that can provide:

- protection from the hazards of new mission environments
- appropriate pressure to eliminate bends risk and pre-breathe
- near-nude body mobility with minimal fatigue
- long-term durability and reliability
- wearer comfort and confidence
- easy don/doff
- minimal servicing and maintenance
- simple re-sizing

Particular missions are expected to impose their own mission-peculiar requirements. For example, orbital operations will require added protection from radiation and debris impact but the thermal environment is relatively moderate. In contrast, debris and radiation are secondary issues for a Lunar suit, but the extreme hot and cold thermal environment and additional factors such as dust will be the primary design drivers. Mars is a relatively cold environment so thermal protection is expected to be easier to achieve, but the higher gravity will mean that the suit weight will become a key issue.

In all expected environments reliability, comfort, and minimal fatigue will be key issues. However, during orbital operations all objects — tools and tasks — that the crewmember encounters during an EVA will be man-made. Thus, the option exists to design the tool interface to match the capabilities of the glove. Missions such as the geological exploration of a planetary surface may require that the crewmember handle and work with oddly-shaped natural objects, thereby requiring a higher degree of dexterity and tactility. In all cases, durability and thermal protection will be key issues.

Similar to the pressure suit and gloves, there are universal requirements that will challenge the portable life support system technologies. In all cases, the system must accomplish the following:

- minimize the use of expendables
- provide a high level of reliability and safety
- minimize weight and volume by efficient packaging
- provide ease of maintenance and repair during the mission
- maintain all aspects of the micro-climate within desired ranges

Orbital operations will further emphasize minimization of the power requirements and size of any regeneration equipment. The maximum degree of regeneration must be achieved since there will be no local resources which might be utilized to support the system. Because oxygen can be produced from Lunar rock or from the Martian atmosphere, the possibility of using such resources must be considered for planetary missions. In addition, the differences in gravity level and thermal environments will lead to significantly different requirements for the thermal control systems. The metabolic rates during zero-g EVAs are generally low and the Earth orbital thermal environment is quite moderate. In contrast, the Lunar environment has much greater temperature extremes. This fact, combined with the expected need to walk and climb, will produce higher metabolic rates. The Martian surface is relatively cool, even at mid-day, but its higher gravity will require even greater metabolic effort to perform EVA tasks. All of these factors will affect the thermal control system requirements and design.

All aspects of the EVA work system must be considered to provide a cost-effective, routine EVA capability. These include:

- PLSS/suit integration
- EVA airlocks and pump-down systems
- robotics and work-aid interfacing
- mobility systems
- communications, data transfer, and displays and controls
- biomedical issues

Specific mission scenario requirements will greatly affect the specific choices of sub-elements of the optimum EVA work system. For example, EVAs conducted on the moons of Mars will be particularly challenging due to the low gravity level. Development of mobility/translation aids, body restraints, and workstations will require particular emphasis to allow effective use of the EVA resource. Selection among alternative concepts will require an experimental approach. The human performance capabilities of a suit or glove concept will be evaluated by experienced EVA astronauts and empirical performance data will be collected.

1.5 PROGRAM GOALS AND OBJECTIVES

Astronauts on Lunar and planetary missions will explore and collect samples of indigenous materials, assemble, repair and service their habitat and other equipment, and carry out experiments and other studies removed from the immediate confines of their vehicle or base. These extravehicular activities will require an EVA work system consisting of a pressure suit, life support system, and ancillary equipment which will allow the astronauts to move and work comfortably, easily, and efficiently. The system needs to be rugged, reliable, and impervious to dust and other possibly damaging conditions found on planetary surfaces and in planetary atmospheres. In addition, the EVA work system needs to be serviced quickly and easily while requiring minimal resources.

Although space suits and EVA systems have been used in space and on the Lunar surface, the technology base for a rugged, highly reliable, mobile, reusable, and easily serviced EVA suit and compact portable life support system does not exist. Experience with previous manned missions has shown that the capability to perform EVA is an enabling component to mission success and safety. The technology base required to support Lunar and planetary mission EVA will be developed in this Pathfinder element. Carefully quantified requirements for suit weight, mobility, and dexterity (particularly for EVA gloves), and for life support system performance will be developed for a representative range of mission scenarios. Rugged and lightweight materials suitable for very mobile EVA suits and dexterous gloves will be examined, and an improved basis for suit design and manufacture will be developed that is based on scenario-derived requirements and careful analysis of lessons learned with current and previous EVA systems. Technology components for provision of breathable air and removal of metabolic wastes and contaminants, and efficient processes and materials which allow in-situ regeneration will be developed. New concepts in thermal management, personal mobility, improved information display, and improved control systems to support routine extended EVA periods will also be provided. Identification of technology needs for tools, unique end-effectors, and communication systems to allow an EVA crewman to work effectively with robotic assistants will also be identified.

1.5.1 Near-Term Objectives (FY89-FY93)

A near-term objective of this program is to study and thoroughly understand the expected requirements of the missions in question and how these will affect the choices of technology paths to be followed. For example, the atmosphere and the gravity level on Mars will have a significant impact on the design of the Mars EVA portable life support system. Similarly, the radiation environment in high altitude and high inclination Earth orbits will be design drivers for a pressure suit for use in such orbits. Regardless of the choice of mission, any EVA system must provide a pressurized enclosure and a micro-climate control system. Therefore, there are overall requirements for advances in areas such as space suit and glove materials, air revitalization systems, and thermal control systems. Effectively integrating the subsystems with each other as well as with the crew and various automated elements of the EVA work system must always be kept in mind to prevent the development of subsystem technology that is incompatible when considered as an element of an overall system.

Reliable technology for a high mobility, routinely serviceable EVA suit with compact fully regenerable portable life support system will be developed. Early identification of suit structural materials and design of a highly dexterous EVA glove suitable for many scenarios are foreseen. Efficient processes for provision of breathable air and removal of waste from expired air and the onboard regeneration of the waste removal subsystem also will be developed. New concepts in thermal management, personal mobility concepts, and information display and control capabilities for the suited astronaut will be provided. Identification of technology needs for tools, end-effectors, and communications will be completed.

1.5.2 Long-Term Objectives (FY94-FY98)

In the longer term, technologies will be integrated into one or more advanced, lightweight suit and PLSS prototypes. Servicing, maintenance, cleaning, and regeneration concepts will be demonstrated which meet requirements for Lunar and planetary use. Tool, unique end-effector, and communications technology requirements will be defined that are compatible with planetary and Lunar mission requirements. The integrated technology prototypes and supporting technologies will be tested extensively in ground-based facilities and prepared for flight testing as required for proof-of-concepts.

1.5.3 EVA/Suit Flight System Development

The purpose of Project Pathfinder is to push American technology forward while making future successes in space possible. The selection and development of the actual flight hardware will be part of future programs resulting from a national commitment to pursue the manned exploration of the solar system.

1.6 TECHNICAL APPROACH

The Pathfinder EVA/Suit Project led by ARC will be accomplished using the resources of other NASA centers, aerospace contractors, and universities. In addition, particular emphasis will be placed on using expertise developed in other related fields, such as scientific and commercial diving. The Project will also emphasize the development and maintenance of NASA in-house technical expertise to effectively select and manage outside resources, such as contractors and universities. NASA will become a provider of technology, as is done in other OAST programs, rather than simply being a consumer.

The EVA/Suit Project is divided into discrete work areas. The primary divisions are called *elements*, the lower level divisions are *sub-elements* and *task areas*. Details of the Work Breakdown Structure (WBS) and technical discussion are provided in the following sections.

Participating centers will prepare task sheets that describe the specific work to be done in the task areas. These task sheets will be updated each fiscal year as part of the RTOP process that actually implements this Plan. The task sheets will be appended to the Plan once they have been prepared.

The Project will be phased to allow careful definition of requirements, analytical and experimental evaluation, and proof-of-concepts before proceeding to full-scale, integrated system prototypes. Generic EVA technology which can be applied to a wide range of mission scenarios will be identified and used to the greatest practical extent.

The payoff of this project will be to provide a routine EVA capability to mission planners. Once they are assured that an EVA crewmember's work capability will be available as a resource to accomplish a mission's objectives, this means of accomplishing tasks outside the vehicle or base could be traded off against alternative approaches, such as special-purpose robotic devices. A routine, manned EVA capability will often provide the most cost-effective solution with significant resultant savings in the overall cost of a mission. This will occur because an EVA crewmember can perform a wide range of tasks that might otherwise be performed by an array of expensive, limited capability devices. As the robotics state-of-the-art is advanced, it is anticipated that robotic assistants will be developed to aid and eventually supplant the EVA crewmember for many routine, well-defined EVA tasks.

2.0 PROGRAM DESCRIPTION

2.1 WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure for the Pathfinder EVA/Suit Project is illustrated in Figure 2.1-1. It is divided into four sections, shown under the top-level box, Extravehicular Activities/Suit Project. The numbers in the lower left corner of each box are the assigned FY89 priorities relative to the other WBS elements of the same level in the hierarchy. A detailed discussion of each is provided later in this Plan.

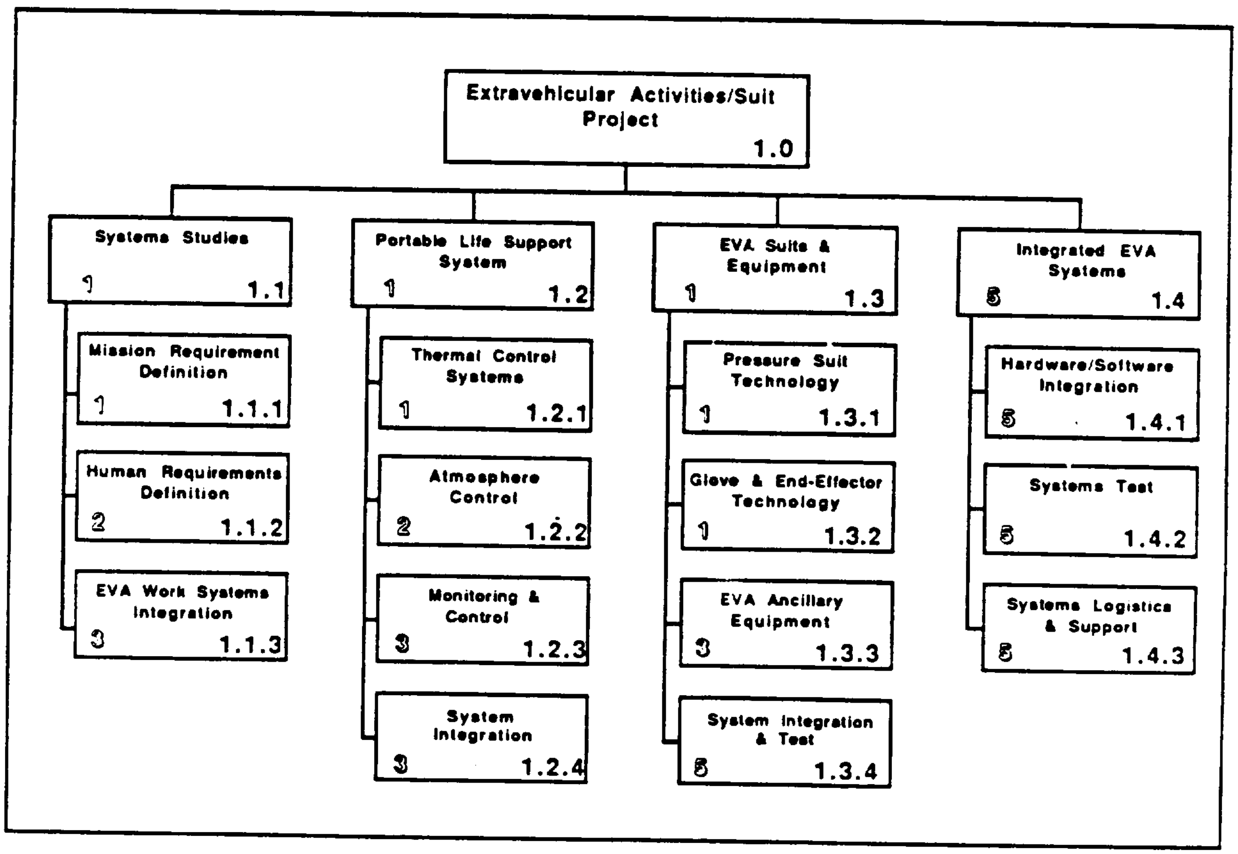


Figure 2.1-1

As shown in Figure 2.1-2, the purpose of the Systems Studies element (WBS 1.1) is to provide guidance and support to the subsystem technology developments. It is a high priority section for FY89 and is further broken down into three sub-elements. The sub-elements cover the work involved with defining requirements, trade-off studies, and planning system integration, support, and testing.

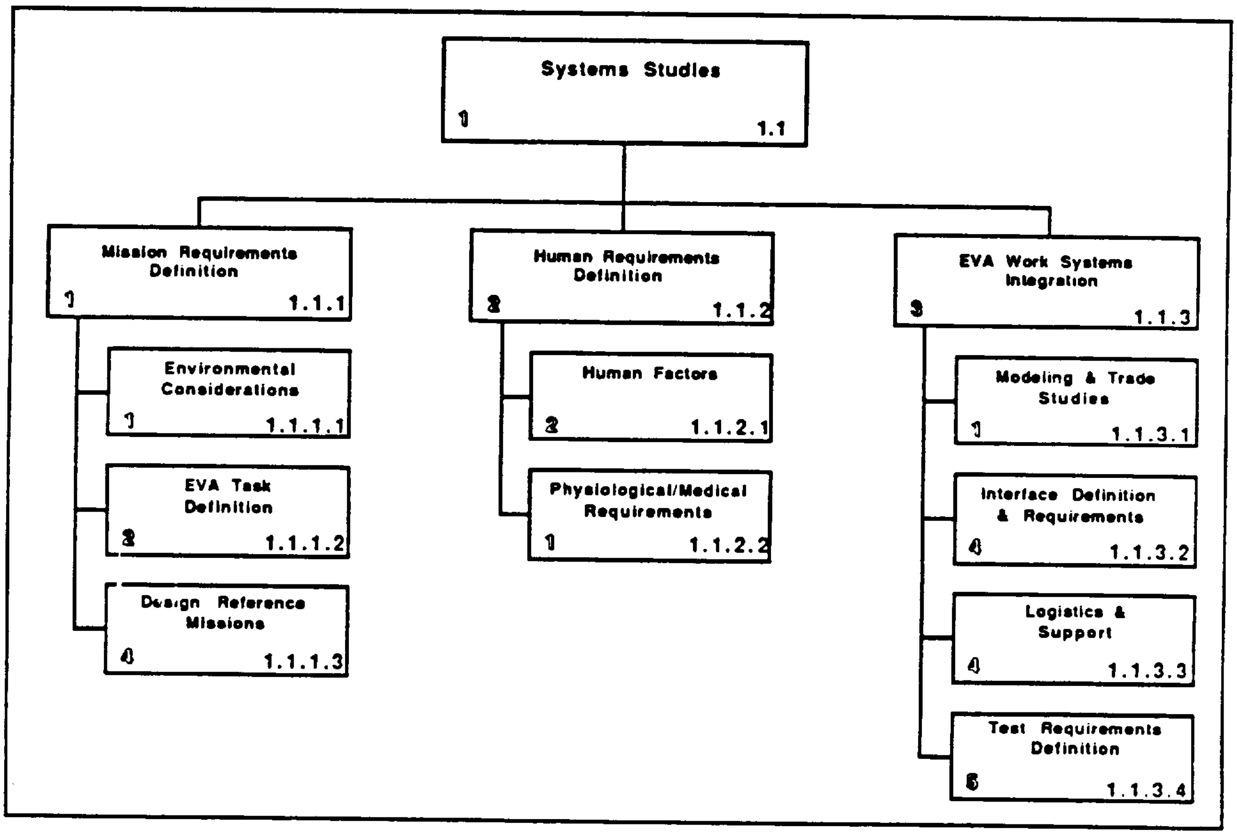


Figure 2.1-2

Mission Requirements Definition: The broad objective of this sub-element is to identify those requirements particular to each mission scenario which can have an impact on EVA systems design.

Human Requirements Definition: The goal of this sub-element is to define and understand the human requirements and capabilities that are relevant to the design and evaluation of all components of the EVA work system.

EVA Work Systems Integration: This sub-element involves identifying those system studies necessary to define and support the integrated EVA system.

Portable Life Support Systems (WBS 1.2) is a large element that is further broken down into four sub-elements as shown in Figure 2.1-3. The sub-elements cover the work involved in technology assessment, requirements definition, conceptualization, modeling, experimentation, breadboard fabrication, testing, and system integration.

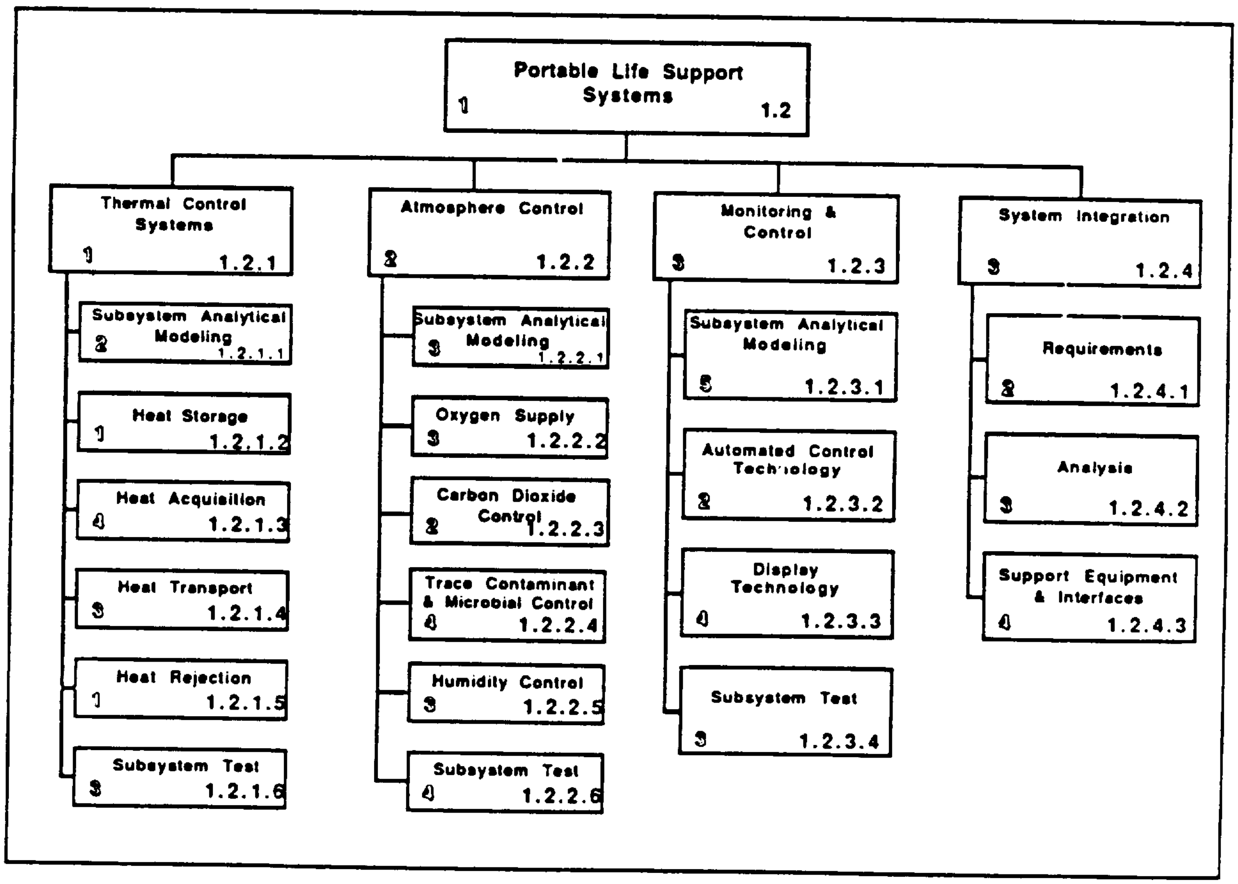


Figure 2.1-3

Thermal Control Systems: The purpose of this sub-element is to develop new technologies and systems for thermal control systems. Concepts to be analyzed and investigated include fusible heat sinks, advanced refrigeration cycles, variable conductance materials, Mars convective heat sinks, superconducting thermomagnetic cycles, and others.

Atmosphere Control: This sub-element is involved with the development of subsystems to remove contaminants from the suit exhaust air. The contaminants are CO_2, water vapor and trace gases produced by human metabolism. Regenerative systems such as electrochemical, metal oxides, vacuum desorbed resins, and others will be investigated.

Monitoring and Control: This sub-element covers work in the development of automated PLSS control and display/annunciator technology. This includes integrated system control, fault detection, trend analysis, and caution and warning for the PLSS system.

System Integration: The goal of this sub-element is to coordinate and provide an integrated systems approach toward the development of portable life support systems. The final proof of any conceptual subsystem is to demonstrate that it will function correctly when integrated into a complete PLSS demonstration system. This sub-element will examine all packaging and integration issues and interfaces and at the appropriate times assemble separately-developed subsystem prototypes into a functional PLSS for demonstration and evaluation.

EVA Suits and Equipment (WBS 1.3) is a critical element that is further broken down into the four sub-elements shown in Figure 2.1-4. The sub-elements cover the work involved in technology assessment, defining requirements, conceptualizing, modeling/experimentation, technology demonstrator fabrication, testing, and system integration.

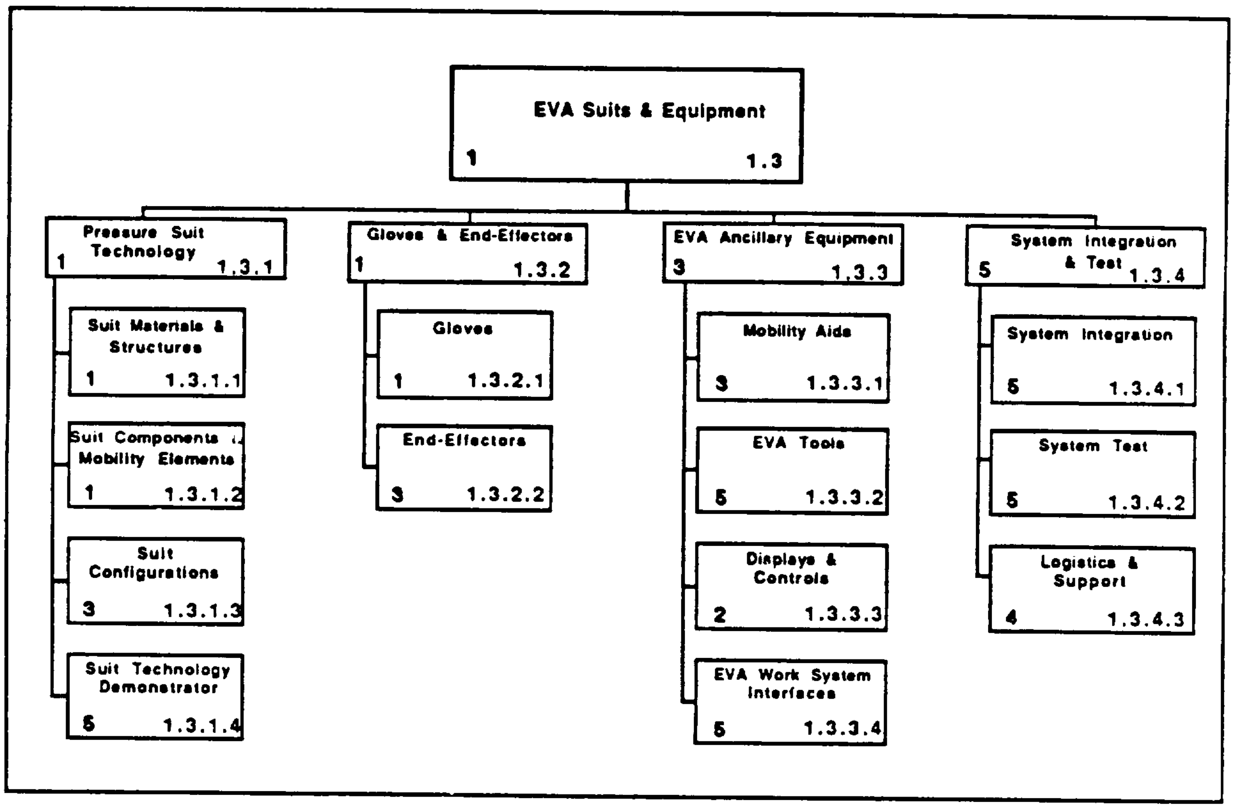


Figure 2.1-4

Pressure Suit Technology: The prime objective of this sub-element is to develop suit technologies which will meet the environmental requirements for extraterrestrial EVA operations. It will include an investigation into the development and use of advanced materials such as reinforced metal matrix castings, ceramics, composites, and polymeric films to form a pressure suit structure. Concepts for advanced mobility joints and integrated suit assemblies will be investigated using CAD analysis, mock-ups, and conceptual hardware as appropriate. Proof-of-concept testing will be performed using laboratory facilities and reduced/zero gravity as simulated by underwater and aircraft testing.

Gloves and End-Effectors: This sub-element is aimed at the development of glove and end-effector technologies that will enhance EVA productivity. It will concentrate on areas such as providing the maximum possible dexterity and tactility with minimum fatigue and the greatest possible comfort. Since the glove is the crewmember's primary task interface, it is inherently a high-wear item. Therefore, emphasis will also be placed on durability and ease of manufacture. Special and general purpose end-effectors will be developed to enhance the crewmember's capabilities for specific EVA mission scenarios.

EVA Ancillary Equipment: This sub-element encompasses the development of specialized systems and equipment designed to aid EVA crewmembers in the performance of their tasks. Specifically, this includes mobility aids, interfaces, communications, and tools. The development of mobility aids will be particularly challenging for relatively high-g environments such as the Martian surface and low-g planetary surface environments such as the Martian moons. Mobility system concepts will be generated and evaluated both analytically and by using mock-ups and simple proof-of-concept test articles. To work effectively, the EVA astronaut must receive information about the work environment and the state of robotic assistants and tools. He must also be able to communicate with and control these devices and access and utilize data from remote locations when necessary. The requirements for such interactions will be identified and concepts will be proven to demonstrate astronaut interaction with all elements of the EVA work system. Particular attention will be devoted to developing effective tools that are carefully integrated with the pressure glove and/or end-effector. A minimum inventory of tools which can perform the greatest range of EVA tasks will be identified and demonstrated by experiment.

System Integration and Test: This sub-element covers the integration and testing of the components of EVA suits and equipment as an integrated system.

Integrated EVA Systems (WBS 1.4), as shown in Figure 2.1-5, is a long-term element that is further broken down into three sub-elements. The sub-elements cover the work involved in system integration, testing, and logistics and support.

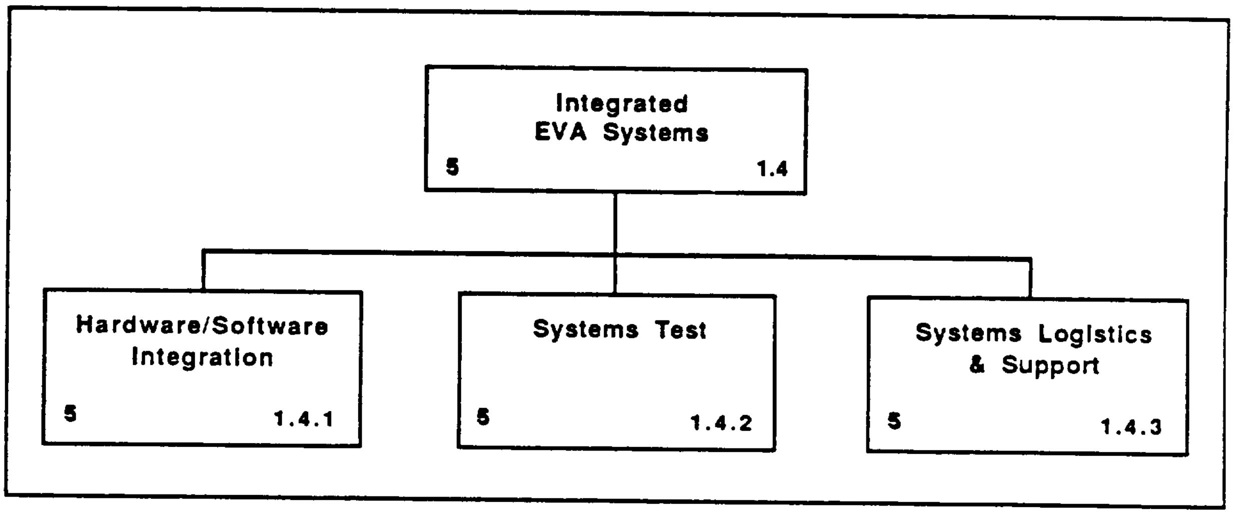


Figure 2.1-5

Hardware/Software Integration: The goal of this sub-element is to coordinate and provide an integrated systems approach toward the development of a unified EVA system, including the space suit, PLSS, and ancillary support equipment.

Systems Test: This sub-element covers work to demonstrate that selected PLSS and EVA suits will safely meet all mission requirements.

Systems Logistics and Support: This sub-element covers two prime areas of emphasis: (1) plan and provide logistics management and support technologies for future EVA operations; (2) application of these technologies to provide support of the technology demonstrator EVA/Suit system.

2.2 MANAGEMENT PLAN

The OAST EVA/Suit Program Plan has defined the roles and responsibilities of the participating organizations. A well organized and controlled project management plan and structure are required in order to develop and demonstrate EVA systems which will safely meet mission requirements in a cost-effective and timely manner within budget constraints. The objective of the EVA/Suit Project Plan is to emphasize the systems-approach philosophy throughout the Project duration to insure that all principal engineers and researchers are cognizant of program goals and mission plans. This Plan will define management structure, coordination requirements, planning, and reporting.

2.2.1 Management Structure

Ames Research Center (ARC) is the designated lead Center for this Pathfinder element and is therefore responsible for project planning and implementation, coordination of the technical interfaces among supporting projects, and implementation of the R&T effort. Johnson Space Center (JSC) will have a major role in developing key technology elements. Support is also anticipated from Langley Research Center (LaRC), particularly in the area of EVA information display technology. The Jet Propulsion Lab (JPL) may also support the project by using their expertise in robotics and end-effectors.

Figure 2.2.1-1 shows the overall management structure. The Headquarters Program Manager (Code RC) is responsible for the strategic guidance of the program, overall management of the fiscal resources, and monitoring to ensure that critical milestones are met. The Program Manager is assisted by the Deputy Program Manager (HQ Code RP) who is specifically responsible for management of the portable life support element. Headquarters will also provide top-level coordination between the Office of Exploration (Code Z) and the Office of Space Science and Applications (Code E) to ensure that their study results and requirements are incorporated into the Program. The Life Sciences Division (HQ Code EB) will be responsible for management of the Physiological/Medical Requirements (WBS 1.1.2.2) task area.

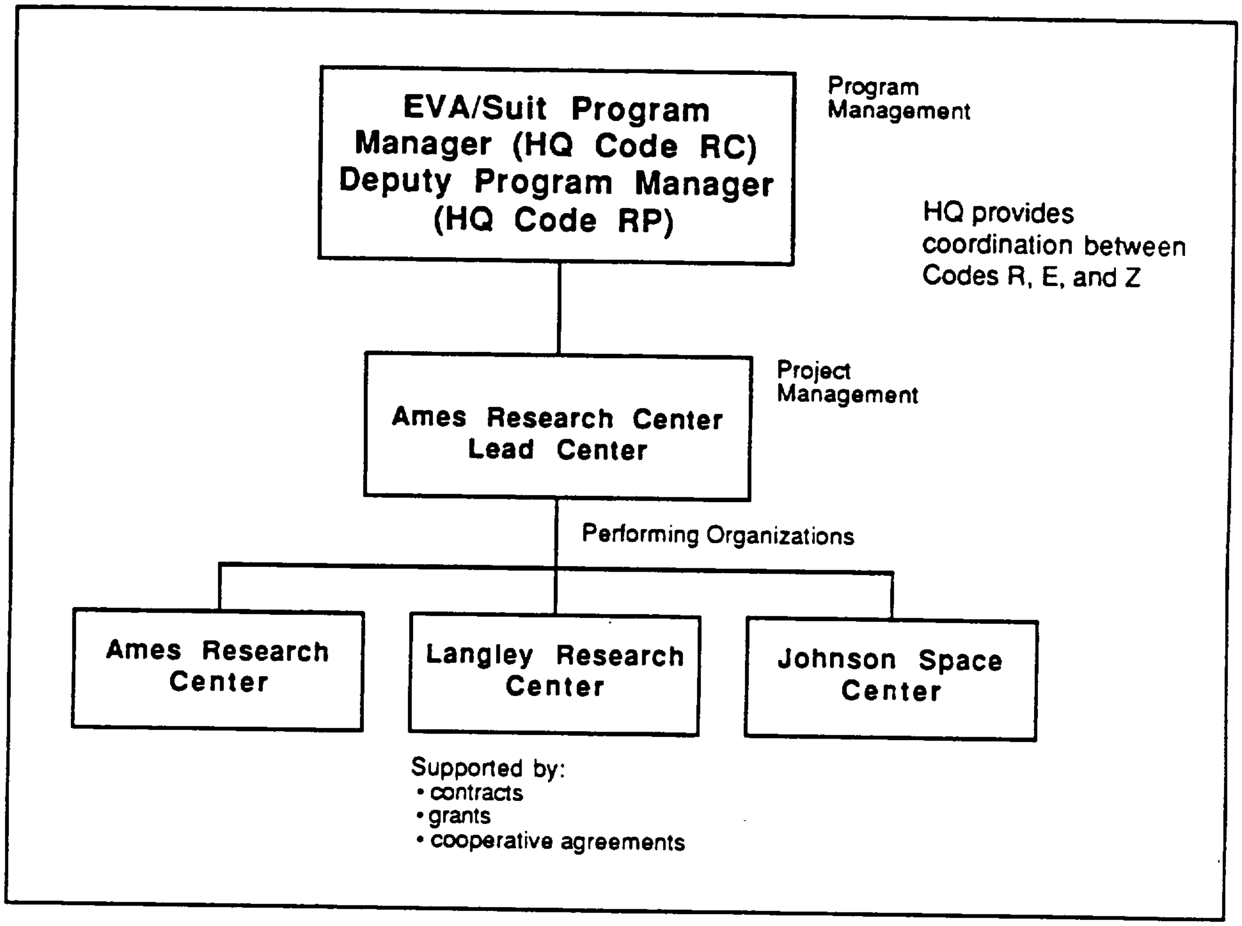


Figure 2.2.1-1

An EVA/Suit Project Manager will be assigned by ARC. This Project Manager will have the responsibility of overall project administration including technical planning, maintaining and reporting schedules and milestones, allocation and management of resources, and facility and staff planning. In addition, the Project Manager will have the authority to resolve issues within the Project.

The Project Manager at Ames Research Center is responsible for the detailed planning, overall management, and actual implementation of the Project. This will include coordination and integration of the EVA/Suit work among the participating centers and top-level direction of the tasks being conducted at the various performing organizations. The technical tasks will be accomplished using a mixture of NASA in-house efforts, contracts, grants, and cooperative agreements. Emphasis will be placed on broadening the base of EVA technology within NASA, private industry, and universities in order to provide a more competitive environment for future EVA hardware procurements.

The ARC Project Manager will appoint an ARC Principal Engineer to each 2-digit WBS element with ongoing effort. It is the responsiblity of each Principal Engineer to oversee and coordinate all tasks in that WBS and to report to the Project Manager, when requested. The ARC EVA/Suit Project management structure is shown in Figure 2.2.1-2.

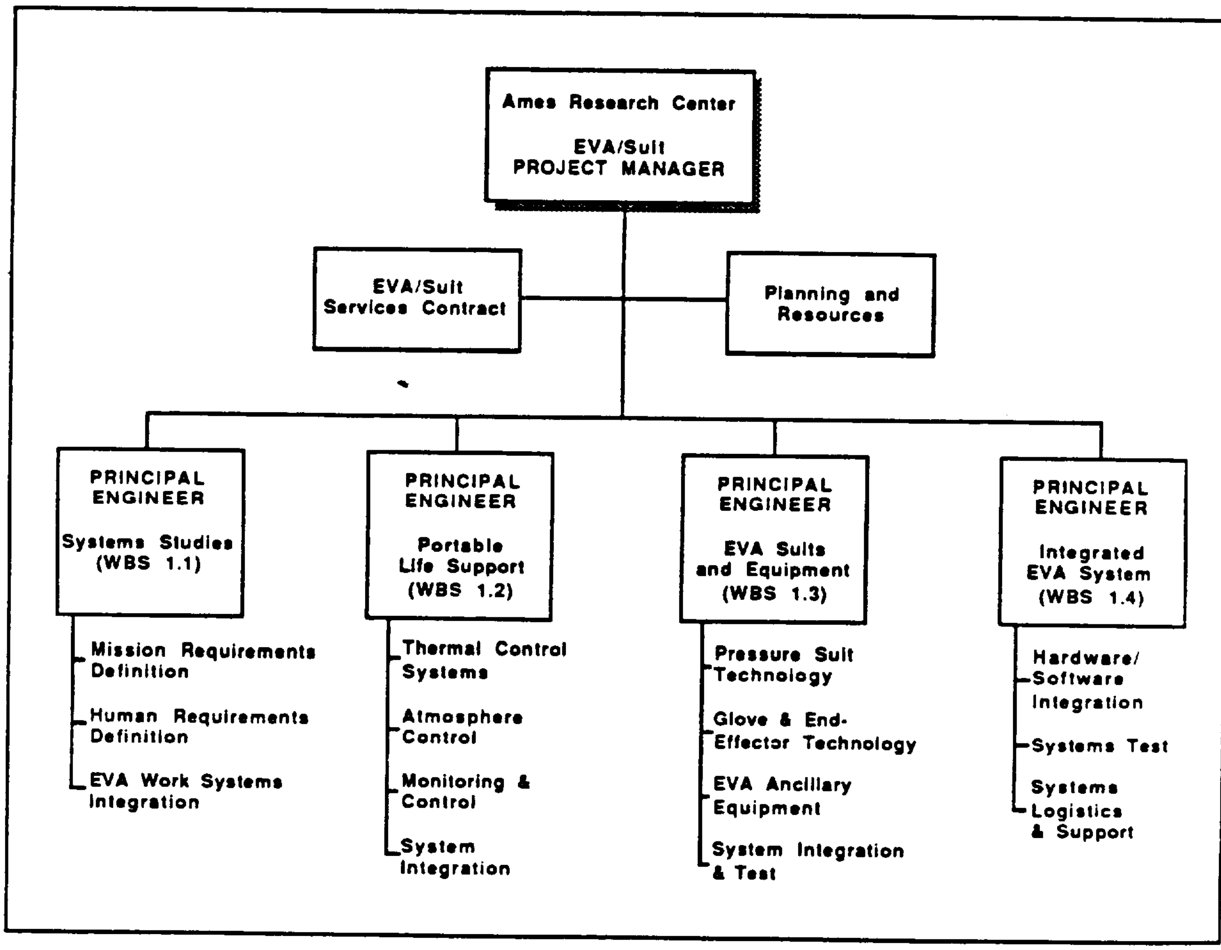


Figure 2.2.1-2

Participating centers include Ames Research Center (ARC), Johnson Space Center (JSC), and Langley Research Center (LaRC). Each participating center will appoint an EVA Manager. The EVA Manager at each center will be responsible to the ARC Project Manager for completion of Project tasks, management of financial resources assigned, and all administrative matters pertaining to reporting and review requirements.

The EVA Manager from each center will be responsible for managing and reporting on all Work Breakdown Structure elements which have ongoing effort at their center. They will make recommendations for funding to the Project Manager and will report on progress for each element during Project Reviews.

As EVA PLSS, suits, and equipment are developed, the ARC Project Manager will insure that all prototype demonstrators meet the system performance requirements established during systems studies. In addition, if competing technologies are developed, the Project Manager (in consultation with the HQ Program Manager) will be responsible for establishing review committees to rate competing systems performance. In addition to system performance, the committees will also be responsible for assessing Project performance issues as part of their review. Project performance issues include factors such as maintainability, reliability, manufacturability, and life cycle cost as well as functionality. The responsibility of the committees will strictly be one of evaluation. The ARC Project Manager will compile the committees' findings and make recommendations to the OAST Program Manager who will have the final authority on selecting which technology to pursue.

2.2.2 Program Coordination

The EVA/Suit Project will be closely coordinated with the Office of Space Science and Applications (OSSA) and the Office of Exploration (OEXP). OSSA will be responsible for establishing human health and biological subsystems integration requirements as guidance to the development of EVA technologies. OEXP will provide mission scenarios to the Project upon which the development of technologies will be based. The status of Space Station EVA systems will be assessed periodically in cooperation with the Office of the Space Station to ascertain the state-of-the art in EVA systems development.

Within OAST coordination will be maintained with the thermal control R&T base program in areas applicable to EVA thermal control technologies and with the Code RP Program Managers for Physical/Chemical Closed-Loop Life Support for technology requirements in the area of portable life support systems for EVA. Coordination will be maintained with Code RM vis-a-vis the Resource Processing Pilot Plant element of Pathfinder in regard to utilization of in-situ resources for life support systems.

Coordination will also be established and maintained with the Department of Defense, specifically the U.S. Air Force and Navy, for the exchange of information and technology in areas common with the NASA EVA/Suit Project.

The EVA/Suit Project requires expertise in many diverse technical areas. At ARC this expertise resides primarily in the Crew Research and Space Human Factors Branch of the Aerospace Human Factors Research Division. Full coordination, cooperation, and support will be maintained with related center activities in Closed-Loop Life Support, Systems Autonomy, and Human Performance. A close working relationship will be maintained with the Astronaut Office at JSC.

2.2.3 Program Planning

The five-year Project Plan as described in this document will be reviewed each year. The annual Project Review will allow re-direction of technical focus as mandated by national plans for space exploration, resource availability, or unexpected technological developments. The yearly review of this Plan will be conducted by OAST, the ARC Project Manager (PM), and the participating centers. The ARC PM will have the responsibility for conducting this review and for modifying, revising, or preparing a new Project Plan document if necessary.

Each year task descriptions including funding requests will be solicited from participating centers. Tasks in the specific work packages will be reviewed by each center's EVA Manager. The EVA Managers will make funding recommendations to the ARC Project Manager. The ARC Project Manager will present proposed resource allocations, milestones and deliverables to the OAST EVA/Suit Program Manager.

2.2.4 Program Reporting

FORMAL REPORTS:

Formal reports to the OAST Program Manager will be the responsibility of the ARC Project Manager. The Management Information Control System (MICS) format will be used for semiannual reports to OAST. Project schedule, progress, and resources expended against total allocated resources will be reported for each center as well as for the overall Project. Participating centers will also present summary reports on EVA technology developments funded by other NASA programs, such as the Space Shuttle and Space Station Programs. Participating centers are responsible for reporting the required information to ARC in Project Reviews conducted at different centers on a rotating basis at least three weeks prior to the OAST review. This will allow time for the ARC Manager to prepare the required reports and address questions which may come up during the Project Reviews. Project Reviews are discussed at length below.

PROJECT REVIEWS:

Project Reviews are the tools the ARC Project Manager will use to implement the systems approach to managing the Pathfinder effort for EVA systems. They will allow the ARC Project Manager the opportunity to keep the Project on schedule and within budget guidelines. In addition, they will provide the participating centers' EVA Managers, who have the first-level responsibility for budgets and schedules, the opportunity to share data, identify promising technology, and avoid duplicated efforts.

Project Reviews will be conducted on a semiannual basis and are scheduled as discussed above to allow enough time for the ARC Project Manager to prepare the OAST review. Each EVA Manager will report on all WBS elements which have ongoing effort at their center. The reports will follow the MICS format discussed above. Under the progress section, each EVA Manager will discuss results to date, identify technological problems, provide plans to address technological problems, and identify administrative issues with suggested corrective-actions plans. The NASA Standard 3000 Man Systems Integration Standards (MSIS) manager will be invited to each meeting. Ultimately, the results of this Project should be incorporated into NASA Standard 3000 to insure that system requirements are distributed to all appropriate parties as they are defined and available for implementation into contractual requirements.

2.3 RESOURCES

2.3.1 Five-Year Funding

Table 2.3.1-1 presents the financial resources required to conduct this Project through FY93. Both the total funds per fiscal year and the distribution of funds among the various Project elements are provided. These funds will be distributed between the various performing organizations in a manner determined by ARC in its role as lead center in collaboration with the HQ Program Manager. Initial projections for this distribution can be found in the Resource Allocation in Section 2.8. The distribution and time-phasing of funding among the technical elements corresponds with the Project technical flow and milestones presented in this Project Plan. Note that Integrated EVA Systems (WBS 1.4) has a zero allotment of funds for the initial five years of the Pathfinder Project. Some functions of this element are included in WBS 1.1 for tabulation purposes. Future planning will shift funds from WBS 1.1 to WBS 1.4 as prototype subsystems are developed.

Table 2.3.1-1 Financial Resource Allocation

Project Element	Fiscal Year ($K)				
	89	*90*	*91*	*92*	*93*
WBS 1.1 Systems Studies*	450	500	500	500	500
WBS 1.2 Portable Life Support Systems	460	2,000	3,600	3,600	3,600
WBS 1.3 EVA Suits & Equip.	210	1,750	2,400	3,150	3,900
WBS 1.4 Int. EVA Systems	0	0	0	0	0
OAST (Code RC) Funds	820	3,750	6,000	6,750	7,500
OSSA (Code EB) Funds	300	300	300	300	300
Total Funds	1,120	4,250	6,500	7,250	8,000

* *assumes $300K from HQ Code EB*

The inter-center distribution for FY89 through FY93 is outlined in Table 2.3.1-2.

Table 2.3.1-2 FY89-FY93 Financial Resource Distribution by Center

Center	Fiscal Year ($K) 89	90	91	92	93
Ames Research Center	560	2,100	3,235	3,530	4,230
Johnson Space Center	560	2,075	3,115	3,670	3,620
Langley Research Center	0	75	150	100	150
Total Pathfinder Funds	1,120	4,250	6,500	7,300	8,000

The ARC human resource requirements to support this Program are provided in Table 2.3.1-3.

Table 2.3.1-3 ARC Staff Requirements

Fiscal Year	Total Staff Required *	Δ (referenced to FY88)
88	3	0
89	8	5
90	11	8
91	15	12
92	15	12
93	15	12

** Funding requirements are predicated on the assumption that the increase will be civil service complement. To the extent that this does not occur, additional funding will be required for additional contractor support personnel.*

2.3.2 Fiscal Year 1989 Funding

The detailed funding distribution for FY89 is tabulated in Table 2.3.2-1 by WBS element and by center.

Table 2.3.2-1 FY89 Funding by Center

Element	ARC	JSC	LaRC	FY89 Total
1.1 Systems Studies				460
1.1.1 Mission Reqmts. Definition	0	0	0	0
1.1.2 Human Reqmts. Definition *	200	200	0	400
1.1.3 EVA Work Systems Integration	0	60	0	60
1.2 Portable Life Support Systems				460
1.2.1 Thermal Control	185	100	0	285
1.2.2 Atmosphere Control	25	100	0	125
1.2.3 Monitoring & Control	50	0	0	50
1.2.4 System Integration	0	0	0	0
1.3 EVA Suits & Equipment				200
1.3.1 Pressure Suit Technology	100	100	0	200
1.3.2 Gloves & End-Effectors	0	0	0	0
1.3.3 EVA Ancillary Equipment	0	0	0	0
1.3.4 System Integration & Test	0	0	0	0
1.4 Integrated EVA System	0	0	0	0
Pathfinder Total *	560	560	0	1,120

* *assumes a total of $300K from HQ Code EB*

2.4 SYSTEM STUDIES

2.4.1 Mission Requirements Definition

2.4.1.1 Objectives

The broad objective of the Mission Requirements Definition (WBS 1.1.1) sub-element is to identify those requirements particular to each mission scenario which can or will have an impact on EVA systems design. Since many other EVA system design efforts are dependent on the specification of these parameters, this effort will be given high priority in FY90.

This effort will be organized into the following approach:

Environmental Considerations (WBS 1.1.1.1):

- Thermal
- Radiation
- Planetary surface characteristics
- Atmospheric considerations
- Gravity field considerations
- Possible contaminants

EVA Task Definition (WBS 1.1.1.2):

- Planned vs unplanned
- Criticality
- Difficulty

Design Reference Missions (WBS 1.1.1.3):

- Detailed mission scenarios

As the data requirements are established, they should be incorporated into NASA Standard 3000 Man Systems Integration Standards. This will insure that the evolving requirements are distributed to all necessary parties in a timely fashion.

2.4.1.2 Technical Approach

Emphasis will focus on review of data from previous studies and missions to establish EVA system design guidelines. Extensive data on environments must be collected to plan missions which include extended periods of planetary surface operations. Previous manned Apollo missions provide an initial Lunar database which requires review and may require expansion for system design requirements. Unmanned Viking missions may not provide a broad enough Mars database to design the necessary equipment and identify operational requirements for Mars missions. If the review indicates that there are parameters for which little or no supporting data has been collected, then either analytical studies or experiments for unmanned probes will be defined to fill in the gaps.

To establish and define EVA tasks, information collected from previous Lunar and Mars missions will be compiled and evaluated to determine what has been learned and how EVA tasks may be adapted. Modeling and trade studies performed in EVA Work Systems Integration (WBS 1.1.3) concerning the utilization of human control with machine control for reasons of safety, cost effectiveness, and productivity will identify an optimum mix of human and machine resources. Much work is required to anticipate and design tasks for a manned mission to previously unexplored planets. With new mission scenarios, EVA remains the method of choice since lack of first hand experience often precludes the use of autonomous systems. Task design is also dependent on research results generated from the Human Requirements Definition (WBS 1.1.2) sub-element. Efforts will be reviewed through inter-center Technical Interchange Meetings to discuss results to date and facilitate data exchange. The NASA Standard 3000 manager will be invited to these reviews.

Design reference missions provide complete, detailed requirements for each mission scenario and represent the culmination of the effort under mission requirements. As reference missions are developed, the specifications generated are incorporated into the test requirements for PLSS, EVA suit, and equipment tests. Testing will then verify that design concepts will meet design reference mission requirements. The requirements in turn are incorporated into Integrated EVA System Tests (WBS 1.4.2) to verify that integrated prototype systems will meet mission requirements.

Design reference missions are synthesized from the scenario studies, the mission environment, and EVA task definitions. Although data will be collected and quantified for the environment in FY90, EVA tasks may not be defined until FY91. Although initial scenarios will be drafted in FY90, reference missions cannot be finalized without input from studies on EVA Work Systems Integration (WBS1.1.3). Final design reference missions are thus projected for completion in FY93.

2.4.1.3 Description

Environmental Considerations (WBS1.1.1.1): Comprehensive studies will be initiated to define unique EVA mission environment parameters relevant to Lunar and Mars manned surface operations. Human factors specialists will focus on directing their studies toward combined environmental effects. Environmental parameters to be defined will include but not be limited to:

- Thermal environment
- Radiation
  - background radiation
  - solar flares
  - cosmic radiation
- Micrometeoroid/secondary ejecta

- Surface characteristics
  - soil type
  - sand and dust
  - topographical/terrain influences
- Atmospheric considerations
  - pressure
  - composition
  - seasonal and diurnal variations
  - wind
- Gravity field considerations
- Static charge potential
- Possible contaminants
  - chemical
  - microbial

EVA Task Definition (WBS 1.1.1.2): Comprehensive studies will be initiated to define EVA mission task requirements relevant to Lunar and Mars manned surface operations as defined by Code Z studies. Based on the results of these studies, specific tasks will identify and define the types of suits, PLSS, and EVA ancillary equipment necessary to support the task. Each task will be categorized with respect to class, criticality, difficulty, and operations to aid in definition of design reference missions. These are described as follows:

EVA Class. The two basic classes of EVA are: 1) Planned EVA — the accomplishment of tasks included in the timeline to support mission operations; and 2) Unplanned EVA — the accomplishment of tasks not included in the timeline, but required to achieve mission success, mission enhancement, or to support contingency operations.

Criticality. An EVA task may be placed in one of three criticality categories: 1) Mission Enhancement — tasks resulting in increased productivity, usually 'piggy backed' onto more important tasks; 2) Mission Success — tasks required to achieve mission objectives; or 3) Safety Critical — tasks that must be accomplished to ensure the safety of the space module or crewmembers.

Difficulty. Three difficulty categories dictate the complexity of an EVA task: 1) Simple tasks using standard tools and posing no risk of exposure to unique hazards; 2) Intermediate or specialized tasks requiring additional tools or equipment, but are procedurally simple; or 3) Complex tasks requiring a significant extension of capabilities (ie, specialized tools, access or restraint problems, extended duration or unrestrained translation).

EVA Operations. Certain operations require the use of EVA: 1) Support — assembly, deployment, positioning and mating/demating of large space structures; 2) Maintenance — equipment positioning, replacement and inspection; activate/deactivate experiments, retrieve samples, connect/disconnect utilities, make repairs due to damage; or 3) Transfer of equipment, personnel and cargo.

Design Reference Missions (WBS 1.1.1.3): Design Reference Missions (DRM) provide complete, detailed EVA system design requirements for each mission scenario and represent the culmination of all mission requirement efforts. As reference missions are developed, the specifications which are generated become part of the test requirements for subsystem and integrated system tests.

Subsystem and integrated system test requirements will be derived from the DRM and will verify that prototype hardware meets mission requirements. In turn, test requirements become part of the specification requirements for flight qualified hardware.

2.4.1.4 Schedule

See Figure 2.4.1-1.

Figure 2.4.1-1 Schedule

WBS 1.1.1 MISSION REQUIREMENTS DEFINITION

Project Element	*Fiscal Year* 89	90	91	92	93
• 1.1.1.1 EnvironmentalConsiderations		//////////	//////////		
• 1.1.1.2 EVA Task Definition		//////////	//////////	//////////	
• 1.1.1.3 Design Reference Missions		//////////	//////////	//////////	//////

2.4.1.5 Milestones and Deliverables

See Figure 2.4.1-2.

Figure 2.4.1-2 Major Milestones and Deliverables

WBS 1.1.1 MISSION REQUIREMENTS DEFINITION

Project Element	*Fiscal Year* 89	90	91	92	93
• 1.1.1.1 Environmental Considerations					
- Requirements report			Δ		
• 1.1.1.2 EVA Task Definition					
- Initial tasks defined/described		Δ			
- Finalized task descriptions			Δ		
• 1.1.1.3 Design Reference Missions					
- Initial missions identified		Δ			
- Revised mission descriptions			Δ	Δ	
- Finalized design reference missions					Δ

2.4.1.6 Resource Allocation

See Table 2.4.1-1.

Table 2.4.1-1 Resource Allocation

WBS 1.1.1 MISSION REQUIREMENTS DEFINITION

	Fiscal Year ($K) 89	90	91	92	93
1.1.1.1 Environmental Considerations					
ARC	0	100	50	0	0
JSC	0	100	50	0	0
total	0	200	100	0	0
1.1.1.2 EVA Task Definition					
ARC	0	0	50	50	0
JSC	0	100	50	50	0
total	0	100	100	100	0
1.1.1.3 Design Reference Missions					
ARC	0	0	0	0	0
JSC	0	0	50	100	100
total	0	0	50	100	100
Total for Project Sub-Element	0	300	250	200	100

2.4.2 Human Requirements Definition

The understanding and definition of human requirements and capabilities are particularly important in the design of EVA systems and equipment due to the very close coupling between the crew and the system. For example, the pressure suit must be comfortable and carefully fitted to a variety of different size subjects yet still allow the greatest possible mobility with the least possible effort. Therefore, the human biomechanics of motion and anthropometrics must be carefully considered during suit design. Similarly, the portable life support system must be designed to accommodate wide variations in metabolic rate that occur during an EVA. Thus, metabolic requirements to perform a given EVA scenario must be known before the system can be designed.

It is the role of the Life Sciences Division of OSSA to conduct the physiological and medical requirements research that will lead to an understanding of the human requirements and capabilities in the space environment that are relevant to the design of EVA systems. The Physiological/Medical Requirements (WBS 1.1.2.2) task area of the EVA/Suit Project will be managed by HQ Code EB while the overall direction is provided by the OAST Code RC Program Manager.

2.4.2.1 Objectives

The overall objective of the Human Requirements Definition (WBS 1.1.2) sub-element is to define and understand the human requirements and capabilities that are relevant to the design of all elements of the EVA work system. The work system consists of the pressure suit and gloves, end-effectors, PLSS, tools, and ancillary equipment such as mobility aids, displays and controls, and robotic interfaces. Research will be conducted in the areas of human factors and physiological/ biomedical requirements definition. The research will be specifically focused on defining quantitative requirements that are necessary for system design and performance enhancement. Emphasis will be placed on this area early in the Project so that results will be available for use during conceptual systems development.

2.4.2.2 Technical Approach

Many hours of EVA experience have been gained in past programs beginning with Gemini and extending through today's Shuttle program. The majority of these EVA hours have been in the zero-g, earth orbital environment with limited experience on the Lunar surface. As a result, the human problems associated with zero-g operations are relatively well understood although some work remains to be done in a few key areas. However, this is not the case for operations on planetary surfaces such as the moon, Mars, or the surface of the Martian moons.

During the Apollo program, a great deal of effort was directed toward studies and simulation of Lunar EVAs. Experiments were performed that simulated the thermal and gravitational environment to examine factors such as the metabolic rate to be expected during an EVA and the thermal comfort of the crewman. More general studies, for example, an examination of the biomechanics of walking in 1/6-g unencumbered by a space suit, were not done. This was appropriate at the time because the Apollo program schedule did not include enough time for a carefully paced, cost-effective approach to system design and optimization. Furthermore, the state of technology in fields such as pressure suit design was very limited so that the primary program emphasis had to be directed toward simply getting the job done safely using the available technology. Few options were available; therefore, little attention was directed at optimization. No work to date has been directed toward EVAs on Mars or its moons.

Design optimization of the EVA system will be much more important for Pathfinder missions than it has been for earlier programs for two reasons:

- Lunar operations will become much more routine and missions will be of greater duration. Design compromises that could be tolerated for short missions will be unacceptable.

- The remoteness and duration of Mars missions will require that every element of the mission be optimized for function, reliability, and efficiency.

Human requirements and capabilities for EVA operations in these environments must be fully understood before hardware elements can proceed beyond the proof-of-concept stage.

The Human Factors (WBS 1.1.2.1) task area includes topics such as sizing and comfort. These are well understood; therefore, relatively little work needs to be done in these areas, particularly in the early years of the Project. The Human Factors task area will emphasize two areas wherein the acquisition of more fundamental knowledge will yield large improvements in the capabilities of the EVA work system. The two areas are the:

- quantification of human range-of-motion and force capability in the mission environment
- examination of the biomechanics of locomotion and task performance in the same environments

The products of the first area will be quantitative pressure suit design guidelines and a database that will provide mission planners with a reliable indicator of the crew's ability to accomplish specific tasks. The biomechanics area is particularly important for planetary operations since the EVA equipment will be worn and operated by astronauts who are walking, riding, and working in gravities of up to 1/3-g. The system mass and distribution of mass will be key design factors. It may be found, for example, that the optimum pressure suit for Martian EVAs might have a non-constant volume lower torso so that the suit would help to support the weight of the suit and the PLSS. This would be quite different from a zero-g suit that should have the greatest possible mobility and range of motion in order to take full advantage of human capabilities in that environment. Full definition and utilization of human capabilities in the specific mission environment will yield obvious payoffs in the improvement of EVA work system effectiveness.

Better knowledge of physiological and biomedical requirements (WBS 1.1.2.2) will improve system safety for more autonomous operations as well as allowing more compact and efficient system designs. For example, during Mars missions EVAs will be performed with no possibility of real-time monitoring from Earth due to the long time delay in communications. In addition, the crew size will be limited so that it will be difficult to devote dedicated intravehicular activity (IVA) time to a function such as routine EVA medical monitoring. The EVA system must include the appropriate on-board medical monitoring systems to allow autonomous operations to the greatest possible extent with a highly flexible and intelligent caution and warning system to alert both the EVA and IVA crew to dangerous trends or medical emergencies. The design and development of such a system will require considerable attention to obtain the greatest capabilities from the most compact and unobtrusive system.

It may be possible to develop an on-board monitoring system that has the ability to determine the actual crewmember metabolic rate in real-time. This would be particularly useful for planetary operations where the metabolic rate will vary greatly during an EVA. This will occur because tasks and activities will range from sedentary activities like driving a small vehicle, to strenuous tasks like climbing to obtain geological samples. Allowable limits for such activities in the anticipated environments must be well established by experiment and analysis.

Biomedical requirements also have a profound, but often hidden, influence on the design of the PLSS. For example, the specification for the maximum allowable CO_2 partial pressure has a tremendous influence on both the size and the type of CO_2 control system in the PLSS. The physical size of the system is inversely proportional to the maximum allowed CO_2 level. The higher the allowed level, the smaller the control system becomes. A more subtle benefit of a higher allowable level is that the number of candidate systems increases as the allowable level is increased. This occurs because the driving potential for CO_2 separation or reaction is the partial pressure. There are candidate systems that can not remove CO_2 at the currently required level, but are effective scrubbers at slightly higher PCO_2. Such candidate systems are not even considered, regardless of these other desirable attributes. For these reasons, the effects of various CO_2 levels and exposure times must be carefully understood before arbitrary requirements are specified.

The selected sub-tasks in Human Requirements Definition must begin in FY89 so that the results will be available in time to guide other phases of the Project. It is anticipated that most of the work in the physiological/medical requirements area can be accomplished by academic studies and interpretation of data already in the literature with relatively little need for experimentation. In contrast, little work has been done in the biomechanics/human factors area, requiring new techniques be developed and unique experiments be performed.

2.4.2.3 Description

The tasks in this Human Requirements Definiftion sub-element will be performed using a combination of NASA in-house expertise with the appropriate support and collaborative agreements and grants with academic institutions. New collaborative tasks will be started at both ARC and JSC in the biomechanics and Human Factors (WBS 1.1.2.1) area. Facilities such as the JSC Anthropometric and Biomechanics Laboratory and the ARC EVA Physiological Research Facility will be utilized to perform these tasks. It is anticipated that JSC with its operational medicine experience will have the leading role in defining the Physiological/Medical Requirements (WBS 1.1.2.2) area. Specific tasks in both areas will be jointly planned by researchers at both centers to minimize duplication of effort and to make the maximum use of the available resources. For example, water immersion facilities which exist at both centers may be useful in investigating locomotion during simulated reduced gravity. A collaborative research project will be produced which will use these and other simulation facilities, such as zero-g aircraft, to best advantage.

FY89 tasks will be initiated in the following areas:

Human Factors (WBS 1.1.2.1): NASA in-house and contracted experimental studies will begin to define and quantify the human range-of-motion and force capabilities under simulated EVA conditions. Another task will begin to examine the biomechanics of locomotion and work in reduced gravity.

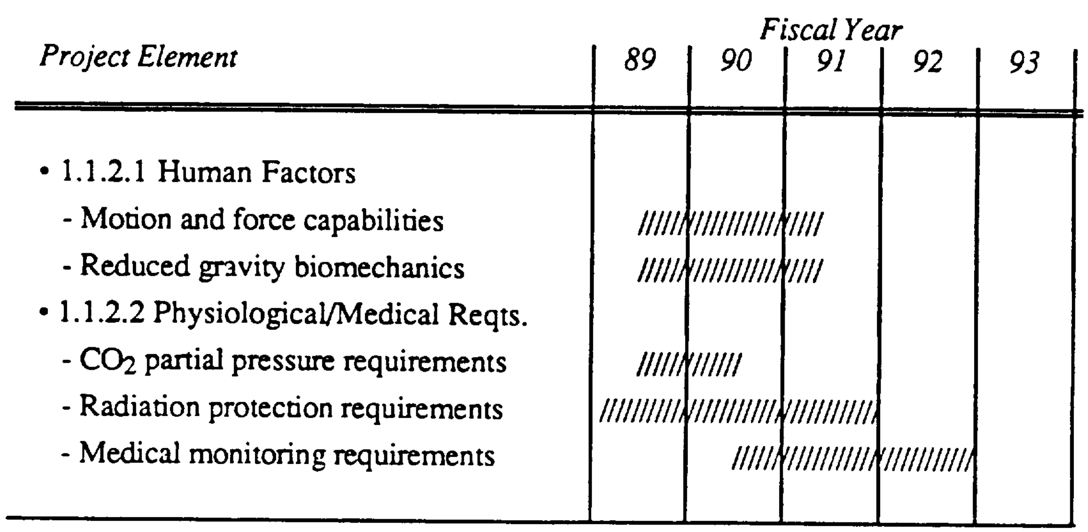
Physiological/Medical Requirements (WBS 1.1.2.2): A task will begin to define the effects of CO_2 partial pressure on system design. An additional task will begin to enhance the modeling capability for radiation protection in different EVA environments.

2.4.2.4 Schedule

As previously mentioned, tasks in the Human Requirements Definition (WBS 1.1.2) area must begin in FY89. The schedule for these activities is provided in Figure 2.4.2-1.

Figure 2.4.2-1 Schedule

WBS 1.1.2 HUMAN REQUIREMENTS DEFINITION



2.4.2.5 Milestones and Deliverables

Key milestones and deliverables are given in Figure 2.4.2-2.

Figure 2.4.1-2 Major Milestones and Deliverables

WBS 1.1.2 HUMAN REQUIREMENTS DEFINITION

Project Element	*Fiscal Year* 89	90	91	92	93
1.1.2.1 Human Factors					
• Report on baseline range-of-motion & force capabilities			Δ		
• Definition of locomotion in reduced gravity			Δ		
1.1.2.2 Physiological/Medical Requirements					
• CO_2 partial pressure requirements study report		Δ			
• Upgrade radiation modeling capability		Δ			
• Radiation protection requirements for Pathfinder missions			Δ		
• Definition of medical monitoring requirements				Δ	

2.4.2.6 Resource Allocation

Resources to perform the work are given in Table 2.4.2-1.

It is anticipated that the financial resources will be provided from both OAST (Code RC) and the OSSA (Code EB). It is assumed that Code RC will fund the Human Factors (WBS 1.1.2.1) task area and Code EB will fund the Physiological/Medical Requirements (WBS 1.1.2.2) task area. Details of the funding plans will be provided with the specific RTOP task submittals.

Table 2.4.2-1 Resource Allocation

WBS 1.1.2 HUMAN REQUIREMENTS DEFINITION

	Fiscal Year ($K)				
	89	*90*	*91*	*92*	*93*
1.1.2.1 Human Factors (Code RC funded)					
ARC	50	75	TBD	TBD	TBD
JSC	50	50	TBD	TBD	TBD
total	100	125	150	150	150
1.1.2.2 Physiological/Medical Requirements (Code EB funded)					
ARC	150	150	150	150	150
JSC	150	150	150	150	150
total	300	300	300	300	300
Total for Project Sub-Element	400	425	450	450	450

2.4.3 EVA Work Systems Integration

2.4.3.1 Objectives

The objective of the EVA Work Systems Integration (WBS 1.1.3) sub-element is to identify those system studies necessary to define concepts for the integrated EVA system. Mission requirements will be defined in WBS 1.1.1 while human requirements are addressed in WBS 1.1.2. This effort will describe requirements for the integrated EVA system including: concept modeling, trade studies, definition of interface requirements, and initiation of studies for logistics analysis and system test/evaluation methodology. In addition, an integrated testbed philosophy will be established to evaluate EVA technology as prototypes are developed.

This effort is divided into four task areas as follows:

- Modeling and Trade Studies (WBS 1.1.3.1)
- Interface Definition and Requirements (WBS 1.1.3.2)
- Logistics and Support (WBS 1.1.3.3)
- Test Requirements Definition (WBS 1.1.3.4)

As test methods and systems requirements are established, they will be incorporated by mission scenario into NASA Standard 3000 Man Systems Integration Standards. This will insure that evolving requirements are distributed to all parties in a timely fashion.

2.4.3.2 Technical Approach

The emphasis in FY90 will focus on concept modeling and trade studies. Modeling techniques will be reviewed to identify the optimum approach for use in characterizing EVA systems and to provide supportability guidelines to system designers. Detailed logistics studies to evaluate maintainability, reliability, and supportability will be accomplished in FY92 or FY93, as prototype systems are demonstrated and a mission scenario is chosen. However, a review needs to begin now in order to select the appropriate model which will adequately describe the challenging logistics requirements of supporting a manned system on the moon or Mars.

Concepts to simulate partial-g via suspension methods will be addressed in FY89 in Human Factors (WBS 1.1.2.1). As test concepts and methodology are developed and demonstrated in FY90 with current EVA systems, they will be incorporated into EVA systems test requirements for use in evaluating Pathfinder technology. Test methodology and requirements for subsystem and integrated system tests will be established in FY93 in order to support technology demonstrators.

Improvements to motion analysis measurement techniques are also addressed in FY89 in WBS 1.1.2.1. Several state-of-the art motion analysis systems are under review to identify the one with the optimum versatility and capability to capture range-of-motion reach performance of suited subjects. Such a system will be required to operate in all test environments including neutral buoyancy underwater testing, variable-g suspension tests, and KC-135 variable-g testing.

The data collected by the motion analysis system must precisely measure suited subject reach performance. Three dimensional reach performance curves will be generated after a test to provide system designers with quantitative feedback when evaluating suit design modifications.

In addition, the data generated by the motion analysis system should be readily transferrable to anthropometric computer modeling systems such as TEMPUS. Thus space suit motion analysis data will provide an animation script for a selected computer model of a suited subject. This will allow workstation designers using the TEMPUS system to account for reach performance using data taken directly from a human subject in a simulated environment.

Once a motion analysis system is selected in FY90 it will be procured for use. Several experiments will be performed to define test methodology using the motion analysis system and establish a baseline suit performance criteria.

2.4.3.3 Description

Modeling and Trade Studies (WBS 1.1.3.1): Modeling and trade studies on integrated EVA systems will begin in FY89 as subsystem concepts are defined and demonstrated. In addition to the normal trade study comparisons of the functional aspects of alternative system concepts, these studies will begin to address issues such as the reliability, maintainability, manufacturability, performance, and life cycle cost of competing prototype systems. This will allow management and designers to make early conceptual design decisions from a systems approach. This is a proven strategy to fielding an R&D system which is reliable, readily manufactured, easily maintained, and long lasting. Implementing the system approach into the EVA system design process will require aggressive management. An effort to develop a NASA EVA space suit plan containing the systems approach is addressed in WBS 1.3.4.2 for integrated EVA suits and equipment. A similar task should be initiated in WBS 1.2.4.1 for the integrated PLSS.

Pilot studies will be initiated in FY90 to identify and select the analysis technique which is best able to describe the logistics support and requirements of EVA systems. Related logistics management and supportability analysis techniques developed by the Department of Defense, NASA, and industry will be reviewed. These include Reliability, Availability, Maintainability and Cost analysis techniques (RAMCOST), the Navy Integrated Diagnostic Support System (IDSS), the IDSS Adaptive Diagnostic System (ADS), the IDSS Weapon System Testability Analyzer, and the Macro-Economic Model of Space Station Operational Cost (MESSOC).

Once a logistics analysis technique is selected, supportability guidelines will be established and provided to EVA system designers for incorporation into system design criteria.

Methods to test and evaluate logistics supportability will be provided for incorporation into EVA systems integrated test requirements (WBS 1.1.3.4).

Interface Definition and Requirements (WBS 1.1.3.2): This task area will define EVA system interface requirements as prototype systems are developed to allow for standardization and commonality. Interfaces of interest include suit/PLSS connection, glove/end-effector, glove/tools, end-effectors/tools, crew/robotic assistants, and communications networks. This task area is projected to commence in 1990 as conceptual systems begin to be defined.

Logistics and Support (WBS 1.1.3.3): Assessment of logistics management and supportability techniques will be addressed in FY90 in WBS 1.1.3.1. This effort will result in identifying the best analytical modeling method to describe logistics support for EVA systems. In addition, logistics supportability guidelines will be identified and provided to system designers for incorporation into system design criteria. Supportability guidelines will include servicing and cleaning techniques as dust and sand are projected to be major concerns under the current mission scenarios.

Additional logistics support tasks which will be accomplished after prototypes are demonstrated and a mission scenario is chosen include:

- develop EVA crew-systems support and interface concepts
- provide analysis and simulation to optimize supportability
- establish database requirements
- develop integrated logistics management and supportability concepts

Test Requirements Definition (WBS 1.1.3.4): This activity will establish test methodology and requirements for integrated EVA systems based on results of studies and testing accomplished in WBS 1.1.1, WBS 1.1.2, WBS 1.2.4, and WBS 1.3.4. Test methods and requirements will be incorporated into NASA PLSS and Space Suit Standards to identify the minimum requirements for prototype systems in order to safely support mission scenarios. These standards will be used as the requirements to verify integrated system performance in WBS 1.4.2. Once mission scenarios and prototype designs are identified, the standards developed will be used as contract item performance requirements to produce flight qualified hardware.

2.4.3.4 Schedule

See Figure 2.4.3-1.

Figure 2.4.3-1 Schedule

WBS 1.1.3 EVA WORK SYSTEMS INTEGRATION

Project Element	*Fiscal Year* 89	90	91	92	93
• 1.1.3.1 Modeling and Trade Studies					
- Logistics analysis review		//////////	//////		
- Space suit test plan review		/////			
- PLSS test plan review		/////			
- Range-of-motion modeling		//////////	//////////	//////////	//////////
- Prototype hardware trade studies	/////	//////////	//////////	////	
• 1.1.3.2 Interface Definition & Reqmnts.		//////////	//////////	//////////	
• 1.1.3.3 Logistics and Support		//////////	//////////	//////////	//////////
• 1.1.3.4 Test Requirements Definition			/////	//////////	//////////// ///(FY94)

2.4.3.5 Milestones and Deliverables

See Figure 2.4.3-2.

Figure 2.4.3-2 Major Milestones and Deliverables

WBS 1.1.3 EVA WORK SYSTEMS INTEGRATION

Project Element	*Fiscal Year* 89	90	91	92	93
1.1.3.1 Modeling andTrade Studies					
• Logistics analysis review					
- identify best model		Δ			
- provide guidelines to designers			Δ		
• Range-of-motion system			Δ		
• Identify space suit test plan methodology		Δ			
• Prototype hardware trades			Δ	Δ	Δ
1.1.3.2 Interface Definition & Requirements					
• Draft requirements		Δ			
• Develop community standards			Δ		
1.1.3.3 Logistics and Support					
• Dustlock system		Δ			
• Support and interface concepts			Δ		
• Database requirements				Δ	
• Logistic system definition					Δ
1.1.3.4 Test Requirements Definition					
• Draft requirements			Δ		
• Revised requirements				Δ	Δ

2.4.3.6 Resource Allocation

Activity in FY89 will focus on a logistics analysis technique review and development of the evaluation methodology necessary to define a NASA PLSS and Space Suit Standard Test Plan. As results from Code Z scenario studies and WBS sub-element 1.1.1 (Mission Requirements Definition) become available it may be necessary to direct additional resources to task area WBS 1.1.3.1 to perform more detailed, integrated system trade studies beginning in FY91. The current resource allocation is provided in Table 2.4.3-1.

Table 2.4.3-1 Resource Allocation

WBS 1.1.3 EVA WORK SYSTEMS INTEGRATION

	Fiscal Year ($K)				
	89	*90*	*91*	*92*	*93*
1.1.3.1 Modeling and Trade Studies					
ARC	0	25	0	0	0
JSC	60	25	50	25	70
Total	60	50	50	25	70
1.1.3.2 Interface Definition and Requirements					
ARC	0	0	0	25	0
JSC	0	0	0	50	0
Total	0	0	0	75	0
1.1.3.3 Logistics and Support					
ARC	0	50	50	50	50
JSC	0	0	50	25	50
Total	0	50	100	75	100
1.1.3.4 Test Requirements Definition					
ARC	0	0	50	25	40
JSC	0	0	0	50	40
Total	0	0	50	75	80
Total for Project Element	60	100	200	250	250

2.5 PORTABLE LIFE SUPPORT SYSTEM

2.5.1 Thermal Control Systems

The heat rejection systems currently used for thermal control of an EVA astronaut consume between one and two pounds of water per hour. Since many Pathfinder mission scenarios may require extensive EVA for construction, exploration, and scientific purposes, this weight penalty cannot be tolerated. Thermal control systems which can function without consuming any mass will be required for most missions. The currently available regenerable thermal control systems are generally too large or completely unsuited for the types of missions being studied. Significant advances in PLSS thermal control systems technology are necessary to meet anticipated Pathfinder mission requirements. The tasks in the Thermal Control Systems sub-element will analytically examine various candidate concepts and provide proof-of-concept test data to allow the eventual flight systems to be selected with confidence.

2.5.1.1 Objectives

The objective of the work in the Thermal Control Systems (WBS 1.2.1) sub-element is to identify, develop, and validate the satisfactory performance of conceptual thermal control technology and systems that may eventually be used in a Pathfinder prototype PLSS. New and innovative concepts will be created and analyzed using a combination of mathematical modeling and lab experiments. Only concepts which have been carefully screened will be selected for breadboard hardware development. The goal is to establish an inventory of proven, candidate systems which can eventually be traded off by mission planners before any decision is made as to which system to fully develop for use on a particular mission. Such an approach will be very cost-effective since only concepts which have been proven and characterized by relatively inexpensive laboratory and breadboard testing will be considered for the much more expensive flight prototype development.

2.5.1.2 Technical Approach

The primary source of heat in an EVA work system is the astronaut's metabolic heat. An astronaut at rest generates about 100 watts (400 Btu/Hr) of heat which must be removed by the thermal control system. During short periods of heavy work this can easily increase by an order of magnitude. If this energy was not removed by some means, the astronaut would quickly collapse due to hyperthermia. Other life support processes such as CO_2 control may generate additional energy which must be removed and rejected to the environment.

The astronaut's overall heat balance is also affected by the ambient thermal environment, which will vary widely over the full spectrum of Pathfinder missions. The Earth orbital environment is relatively benign from a thermal viewpoint. Except for the occasional contact with objects such as handrails, tools, etc., all heat transfer is by radiation to and from the environment. The astronaut may be exposed to direct sunlight for part of an orbit while simultaneously radiating to deep space. Infrared energy is also radiated from the nearby planet Earth which is relatively cool. In general, the only significant source of environmental heat flux comes from the infrared emissions of nearby hot structures which may trap and re-radiate infrared energy. For example, the proposed Space Station satellite servicing bay would trap considerable infrared energy if it was exposed to the sun with the doors open. EVAs conducted inside such a hot enclosure would require careful protection from the hot environment. Another feature of the low Earth orbital environment is that most structures and objects are not in thermal equilibrium since the external environment is constantly changing due to the orbital motion. In general, the net result is that the orbital heat flux can be controlled using external coatings and/or insulation so that it does not contribute significantly to the system heat load.

The Lunar thermal environment is quite different. The Lunar surface is in thermal equilibrium due to the slow rotation of the moon. Thus, the daytime temperatures may reach 250° F or even higher where the local topography tends to trap thermal radiation (in a crater, for example). This hot surface emits considerable infrared energy in addition to the high contact temperature. An additional problem is caused by the dust which quickly coats the outer surfaces of a pressure suit and tends to increase the amount of infrared energy which the surface will absorb. The net result here is that the Lunar environment at "high noon" is very hot and it will add considerable heat load to the EVA system. Conversely, at night the surface cools to the point where significant heat is lost to the cold environment. Other than during the Lunar morning and evening, which actually last for several days on the moon, the Lunar thermal environment is one wherein it is difficult to isolate the astronaut from the temperature extremes. Therefore, an EVA system designed to be useable at any time during the diurnal cycle must deal with significant environmental heat transfer. Both the pressure suit and the PLSS must be designed to accommodate this "heat leak" into or out of the system.

The thermal environment on Mars is even more exotic. Mars has a significant atmosphere requiring that convective heat transfer be considered. It also has a nearly 24 hour diurnal cycle in which large variations in the ambient temperature may occur during the course of an EVA. However, the atmosphere is "thin" relative to the Earth's so considerable radiant heat is lost to space. The small Martian moons do not have an atmosphere so the resulting EVA thermal environment is expected to be cold. Overall, the Martian thermal environments are complex and have never been studied from an EVA viewpoint.

As the previous discussion has shown, it is necessary to fully understand the EVA ambient thermal environment in order to design all elements of the EVA work system. Therefore, studies will be conducted (WBS 1.1.1) to characterize the environments and provide thermal control design requirements.

The EVA thermal environment affects the PLSS thermal control system in other ways besides the "heat leak" into or out of the system. For example, a space radiator which radiates system-produced heat to the ambient environment can only reject heat if there is a positive heat transfer potential to the ambient environment. Otherwise the radiator will actually absorb heat from the environment. This is a particularly serious problem for a PLSS where the primary heat source is the astronaut's metabolic heat which is mainly produced at temperatures below 85° F. Thus a space radiator for a PLSS would have to reject its heat load at temperatures below 85° to keep the astronaut cool. This is impossible in many EVA environments unless a thermodynamic refrigeration cycle is used to raise the radiation temperature. Of course the inherent inefficiencies of such a cycle add to the ultimate heat load which must be rejected so that the radiator area must increase to handle the extra heat load. If the environment is sufficiently hot, the refrigeration cycle must raise the temperature to such a degree that the cycle efficiency begins to decrease and the actual heat that must be rejected increases even more. The system is in effect "chasing its tail".

The purpose of this discussion has been to illustrate the complex interaction between the EVA thermal control system and the ambient thermal environment. These interactions must be fully understood and carefully considered even at the early stage of conceptual consideration of various thermal control systems.

The overall approach to technology development in this sub-element will be to carefully consider the expected mission requirements at the earliest possible point. It is recognized that HQ Office of Exploration is currently beginning detailed mission scenario studies and that it will be some time before more detailed requirements are available. Elsewhere in this plan (WBS 1.1) studies will be undertaken to produce the more specific requirements and design reference missions that will ultimately be needed for all elements of EVA technology development. In the interim, before more detailed studies are completed, enough generic requirements are known that preliminary conceptual analysis and experiments can begin. This preliminary work will be directed primarily at technologies and concepts that a broad first analysis has indicated should be useful. When the more detailed requirements are available, they will be used to allow refinements to these first generation concepts. For example, a self-contained thermal control system that absorbs heat produced during an EVA without rejecting it to the environment would be attractive for a wide range of mission scenarios. A fusible heat sink is an example of such a concept. Early work will be directed toward the development of fusible heat sink technology in general. This work will then be more specifically directed toward concepts for particular scenarios as the design reference missions are developed. Similarly, compact, highly efficient, advanced refrigeration cycles would have broad application and, therefore, tasks will begin immediately in this key technology area. New concepts and ideas will be sought throughout the duration of the program and they will be analytically screened and compared to existing concepts before a decision is made to begin even conceptual development.

The project is divided into the following six related task areas:

- Subsystem Analytical Modeling (WBS 1.2.1.1)
- Heat Storage (WBS 1.2.1.2)
- Heat Acquisition (WBS 1.2.1.3)
- Heat Transport (WBS 1.2.1.4)
- Heat Rejection (WBS 1.2.1.5)
- Subsystem Test (WBS 1.2.1.6)

Thermal control Subsystem Analytical Modeling (WBS 1.2.1.1) will be done at every stage of the program. Thermodynamic and heat transfer analysis of all concepts will be done before any actual hardware is developed or experiments are performed. This analysis may be done as part of a proposal for a new task in the other 4-digit task areas or in other cases it may be required as part of an existing program. However, the appropriate analysis will be provided to the ARC Project Manager in every case before a commitment is made to pursue a particular technology path. More detailed thermal control subsystem analyses will be performed in WBS 1.2.1.1 as concept development and experiments proceed so that the best possible data and analytical models are available for mission analyses and trade studies. The remaining task areas are each devoted to particular aspects of the PLSS thermal control system.

The EVA thermal control system is conceptually divided into three areas: (1) the acquisition of the thermal energy from the source in which it is produced (metabolic ambient, or instrumentation); (2) transportation of the energy through the system; and, (3) transferring the energy to a heat sink where it is either stored during the EVA or rejected to the environment during the EVA.

As previously mentioned, the primary source of thermal energy in the EVA system is the astronaut's metabolic heat, which is low-grade thermal energy at a temperature in the range of 80-100° F. Since this is low-grade energy, it is not generally useful to store as a source of process heat for system regeneration. This energy can be removed from the body by a combination of mechanisms: convection due to gas flow over the skin, conduction from the skin to a cooled surface in contact with it, radiation to (or from) the pressure suit wall, or by evaporation of sweat from the skin or water evaporation from the lungs. Energy from other sources, i.e. other equipment, may be acquired by similar mechanisms. Extensive experience has shown that in most cases the most practical and effective way to acquire metabolic heat is to use some form of liquid circulation garment which is worn by the astronaut and through which cooled liquid can be pumped. Cooling by means of air circulation has been shown to be generally inadequate for this application. The state-of-the-art in heat acquisition is relatively advanced so that low priority will be given to this area (WBS 1.2.1.3) although promising new concepts may be investigated in the future.

Currently heat is transported within the PLSS by pumping water through the system which has been shown to be practical and effective. Relatively little attention will be to given to this area in the early stages of the project. However, for some applications, there may be a specialized need for a different method of heat transport. Heat pipes are an example. If analysis shows that it is warranted, future developments may be undertaken in this area (WBS 1.2.1.4).

Ultimately, the thermal energy must either be rejected (WBS 1.2.1.5) to the environment during the EVA or stored (WBS 1.2.1.2) and rejected during a later system regeneration. Both of these areas are high priority for early efforts.

Heat may be stored by a system such as a fusible heat sink. Such a system stores heat by using the heat of fusion of a suitable material such as the phase change of ice to water. In this case, the ice is melted by the heat produced during the EVA. The liquid water is stored and refrozen during system regeneration. Such a concept is simple and relatively compact. However, the low heat of fusion of water means that a large mass of water must be carried during the EVA. This is relatively unimportant for zero-g operations, but it may be completely unacceptable for Mars EVAs in 1/3-g. Research in this area will initially concentrate on laboratory and analytical work to identify better fusible materials and proof-of-concept of several analytically proven concepts for high performance fusible heat sinks. New concepts for EVA heat storage will also be pursued (WBS 1.2.1.2).

Heat rejection to the environment may take place in a number of ways. Current systems evaporate (sublimate) water from the PLSS and use the high heat of evaporation to cool the PLSS systems. The water cannot be recovered for reuse, but the heat sink is very compact and reliable. Such a system may still have application in some scenarios where only very limited EVA hours will be required in environments with high heat loads. Current concepts for regenerable heat rejection systems generally use some form of thermodynamic refrigeration cycle. Considerable work will be directed toward analytically and experimentally identifying new, highly efficient refrigeration cycles which can raise the radiation temperature to very high levels and can reduce the radiator area without simultaneously creating cycle inefficiencies which would increase the the heat which must be rejected. Attractive concepts will be selected for proof-of-concept development since such a device could potentially be used over a wide range of Pathfinder mission scenarios. The generally cold Mars environment, which includes the possibility of convective heat rejection to the atmosphere, is particularly interesting and challenging since the relatively high gravity level will mandate that the PLSS be very light weight. Here, a combined convective/radiative heat rejection system may be attractive. Such concepts will be initially explored analytically (WBS 1.2.1.5).

Any thermal control subsystem which survives the analytical and experimental screening must eventually be built and tested. This work element has low initial priority since several lower fidelity analyses and experiments must be completed before full-scale concept testing will commence (WBS 1.2.1.6).

2.5.1.3 Description

FY89 tasks will be initiated in the following areas:

Subsystem Analytical Modeling (WBS 1.2.1.1): Both NASA in-house and contracted analytical studies will be performed to evaluate existing and new concepts for advanced thermal control systems.

Heat Storage (WBS 1.2.1.2): A combination of NASA in-house, contracted, and university programs will be initiated to examine advanced fusible materials and fusible heat sink concepts.

Heat Acquisition (WBS 1.2.1.3): No new work will begin in this area in FY89.

Heat Transport (WBS 1.2.1.4): No new work will begin in this area in FY89.

Heat Rejection (WBS 1.2.1.5): Similar to WBS 1.2.1.2, a combination of resources will be directed to identify, analyze, and experimentally verify new concepts for advanced refrigeration cycles and heat rejection devices.

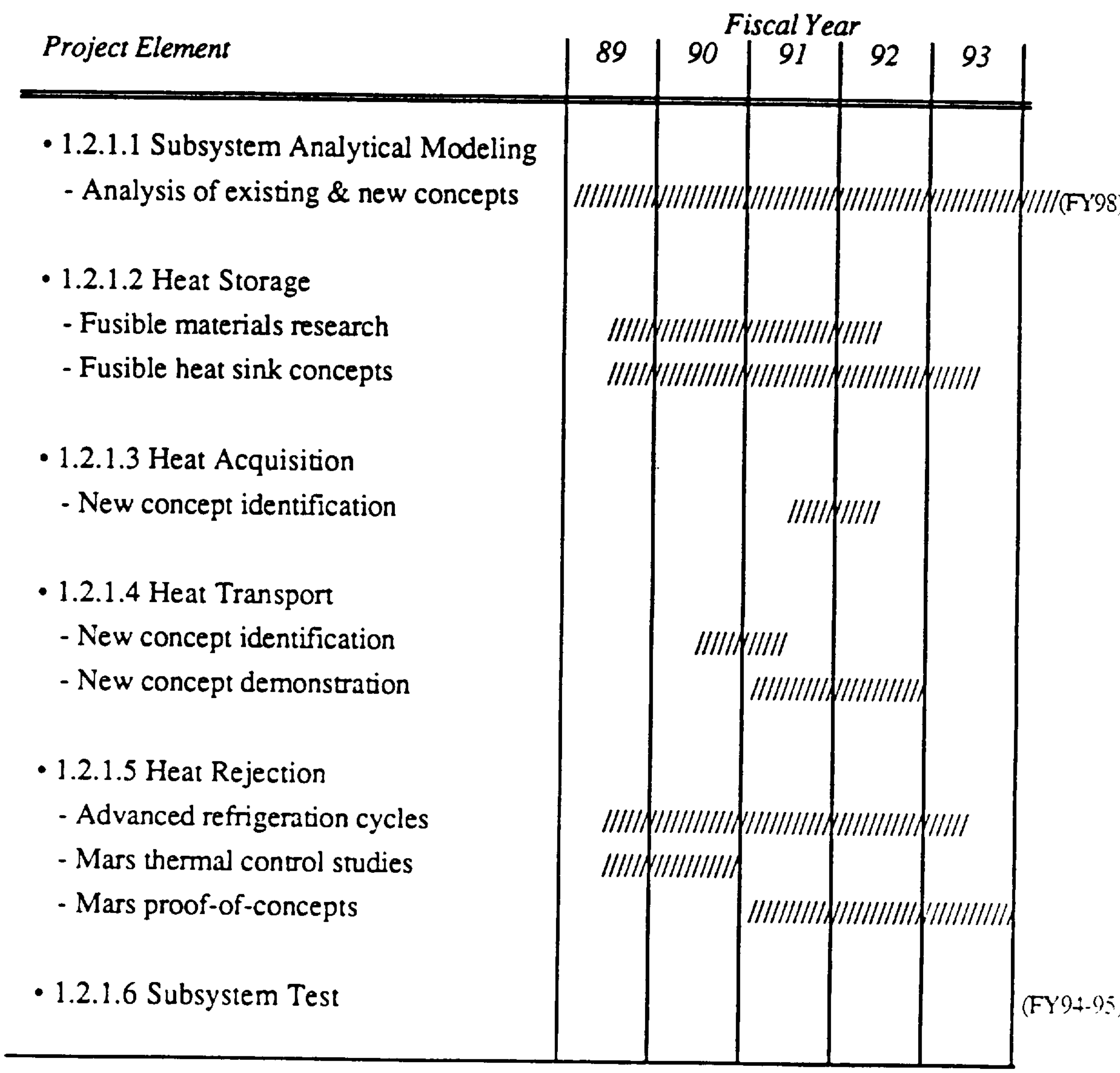
Subsystem Test (WBS 1.2.1.6): No new work will begin in this area in FY89.

2.5.1.4 Schedule

The overall schedule for this sub-element is shown in Figure 2.5.1-1.

Figure 2.5.1-1 Schedule

WBS 1.2.1 THERMAL CONTROL SYSTEMS



2.5.1.5 Milestones and Deliverables

Figure 2.5.1-2 shows the key milestones and deliverables.

Figure 2.5.1-2 Major Milestones and Deliverables

WBS 1.2.1 THERMAL CONTROL SYSTEMS

Project Element	*Fiscal Year* 89	90	91	92	93
• 1.2.1.1 Subsystem Analytical Modeling					
- Complete analysis of current system concepts			Δ		
• 1.2.1.2 Heat Storage					
- Identify advanced fusible materials				TBD	
- Zero-g fusible heat sink concept			Δ		
• 1.2.1.3 Heat Acquisition					
- Report on new concepts				Δ	
• 1.2.1.4 Heat Transport					
- Report on new concepts			Δ		
• 1.2.1.5 Heat Rejection					
- Identify candidate concepts for advanced refrigeration cycles		Δ			
- Proof-of-concept advanced refrigeration				Δ	
- Mars heat sink concepts		Δ			
• 1.2.1.6 Subsystem Test					

2.5.1.6 Resource Allocation

Table 2.5.1-1 shows the distribution of financial resources by task area, by fiscal year, and by performing NASA center. As shown, the resources are evenly divided between ARC and JSC.

Table 2.5.1-1 Resource Allocation
WBS 1.2.1 THERMAL CONTROL SYSTEMS

	Fiscal Year ($K)				
	89	90	91	92	93
1.2.1.1 Subsystem Analytical Modeling					
ARC	35	100	200	200	200
JSC	0	100	200	200	200
Total	35	200	400	400	400
1.2.1.2 Heat Storage					
ARC	75	200	400	400	400
JSC	0	100	150	200	200
Total	75	300	550	600	600
1.2.1.3 Heat Acquisition					
ARC	0	0	50	50	50
JSC	0	0	50	50	50
Total	0	0	100	100	100
1.2.1.4 Heat Transport					
ARC	0	0	0	0	0
JSC	0	100	100	0	0
Total	0	100	100	0	0
1.2.1.5 Heat Rejection					
ARC	75	200	450	450	450
JSC	100	200	400	450	450
Total	175	400	850	900	900
1.2.1.6 Subsystem Test	0	0	0	0	0
Total for Project Sub-Element	285	1,000	2,000	2,000	2,000

2.5.2 Atmosphere Control

2.5.2.1 Objectives

The goal of the Atmosphere Control (WBS 1.2.2) sub-element is to develop simple, reliable subsystems that can be packaged into an easily maintained atmosphere control system comparable in size to the fully expendable systems currently in use. Specifically, it is necessary to:

- identify and develop highly effective chemicals and systems to remove contaminants from the suit exhaust air
- develop technologies for power-efficient, automated oxygen (O_2) replenishment and gas circulation systems

Subsystems for these applications must accomplish the following:

- minimize the use of expendables
- provide the reouired reliability and safety
- minimize weight and volume by efficient packaging
- provide ease of maintenance and repair during the missions(s)
- maintain all aspects of the atmosphere within the desired ranges

The contaminants are carbon dioxide (CO_2), water vapor, and other trace gases produced by human metabolism. Physiological constraints on the subsystem parameters will be determined and substantiated by Code EB. If the CO_2 partial pressure constraint can be relaxed for the advanced EVA systems, allowing a higher CO_2 partial pressure, a greater number of technologies will be able to meet the constraint. Such parameters must be investigated and validated by those with expertise in human physiology.

Mission scenarios will also influence the design of subsystems. The duration and work rate of a typical EVA will vary among missions, affecting the required capacity of subsystems. Mission-specific factors that may influence the design will be a product of WBS 1.1.1.

Design requirements will be determined for each of the proposed missions and analyses will be performed on the candidate subsystems in the relevant environments to quantify performance and to aid in the selection of subsystems for each mission. Breadboard models will be used to demonstrate subsystem concepts before prototype detail design begins. Criteria for the selection of prototype subsystems are weight, volume, power requirements, thermal loads, serviceability, reliability, and safety. As much as possible, detailed design will proceed concurrently with the detailed design of other PLSS components to allow system integration factors to influence the design.

2.5.2.2 Technical Approach

Atmosphere control, as it pertains to the portable life support system, can be divided into six task areas:

- *Subsystem Analytical Modeling (WBS 1.2.2.1)* : Promising concepts and systems will be analytically evaluated.
- *Oxygen Supply (WBS 1.2.2.2)*: The crewman is consuming oxygen at a rate proportional to his workrate. This oxygen must be replenished in the airstream.
- *CO_2 Control (WBS 1.2.2.3)*: The EVA crewman produces CO_2. In a closed system this CO_2 must be removed. The small volume of the PLSS air system provides little damping for changes in gas composition, requiring that CO_2 be removed as fast as it is produced.

- *Trace Contaminant and Microbial Control (WBS 1.2.2.4)*: Small amounts of trace gases and micro-organisms are produced by human metabolism. A means of removal must be provided.

- *Humidity Control (WBS 1.2.2.5)*: Water vapor is a component of expired air. In addition, high EVA-work levels will induce perspiration. All excess moisture must be removed in a closed system.

- *Subsystem Test (WBS 1.2.2.6)* Concepts for aAmosphere Control Subsystems must be integrated and tested.

Each of these primary technology areas is discussed separately because the state-of-the-art and the focus of future efforts is specific to each.

Oxygen Supply (WBS 1.2.2.2.): Oxygen can be stored in combination with other elements in the form of chemical compounds. Reaction of these compounds can be controlled to produce breathable oxygen for EVA consumption. Chemical O_2 storage technology stemmed primarily from the development of submarine atmosphere supplies, aircraft emergency breathing O_2 supplies, and industrial breathing supplies.

The requirements of such a subsystem are that (1) oxygen is released readily with a minimum of contamination by undesirable substances, (2) the reactant is stable in storage, and (3) subsystem operation is safe and reliable.

There are three classes of oxygen producing compounds. The first of these are peroxides and superoxides of metals. In this type of subsystem, peroxides or superoxides of alkali metals react with CO_2 and water to produce a carbonate-bicarbonate salt and oxygen. The method has several drawbacks. The reactions produce too much oxygen relative to metabolic requirements, so exposure to the reactants (CO_2, H_2O) must be controlled, or excess O_2 must be vented. Secondly, the reaction is exothermic (heat producing), creating an undesirable heat load for the backpack thermal control system. Thirdly, the safety of these systems is questionable, as superoxides may ignite if in contact with an organic material.

The second class of chemical oxygen supplies is the chlorates and perchlorates of metals. Oxygen is produced in the thermal decomposition of a chlorate or perchlorate (e.g. $NaClO_3$, $LiClO_4$). These systems have a high oxygen yield but the heat required for maintenance of the decomposition reaction poses thermal problems.

The third class of chemical reactants for oxygen supply is the compound hydrogen peroxide. Oxygen and water are produced in a catalyzed decomposition reaction. This is an exothermic reaction, but has a high O_2 yield. The primary disadvantages of this technology lie in the operational considerations, storage, and handling, since hydrogen peroxide is unstable.

The alternative to chemical storage of oxygen is elemental oxygen storage. The oxygen can be stored in the gaseous state at a high pressure or cryogenically as a supercritical gas or a liquid. Cryogenic methods have a low storage volume and weight, but require a relatively large heat exchanger to warm the gas and/or evaporate the liquid before it is inspired. The total volume of the systems then becomes prohibitive.

Gaseous storage of oxygen in a high pressure vessel is a feasible method of supplying O_2 to the crewmember. The weight and volume of representative systems have been calculated and are acceptable. Storage vessels and pressure regulation techniques for high pressure systems are available and in use today. This technology is mature, reliable, relatively uncomplicated, and can be adapted for Pathfinder missions. A highly efficient, reliable and safe compression technology must be designed to compress the base vehicle O_2 supply for EVA use. This is one focus of future efforts in O_2 supply technology. An issue directly related to O_2 replenishment/air supply is gas circulation. There exists a need for a more efficient, multi-speed fan for the PLSS gas circulation system. Present fans are designed to operate for the maximum EVA workload, and therefore use more power than is necessary at lower EVA workloads. Power can be conserved with a multi-speed fan that is closely coupled to the crewmember's workrate. The technology for this mechanical equipment is established. However, a low level of effort will be required in the future for this design; immediate work is not necessary.

CO_2 Control (WBS 1.2.2.3.): Development of a reliable, simple CO_2 control subsystem is critical in establishing an EVA resource for space exploration. The most important feature in the design of this subsystem is its response time. The EVA pressure suit volume provides little damping for elevated CO_2 levels. It must be removed as fast as it is expired, or the CO_2 partial pressure will rise beyond currently acceptable levels.

The current acceptable levels have been arbitrarily set in the past and adhered to without substantiation. Acceptable CO_2 partial pressure levels must be re-examined by Code E and new guidelines established. It is believed that with a higher allowable level of CO_2 partial pressure a greater number of available technologies can meet that requirement. The low current value limits the technology choices. Determination of this physiological information will establish a critical design driver and technology selection criteria and its importance is emphasized early in this project.

Lithium hydroxide (LiOH) canisters have been used on all U.S. manned space programs to date. LiOH granules chemically bond with CO_2 molecules in the air. However, the crew must be protected from contact with LiOH dust, which is caustic and inflames eye tissue and mucous membranes. This system is not regenerable and as such may be unacceptable for many Pathfinder scenarios.

A closed CO_2 control system both regenerates the CO_2 sorbent and recovers oxygen from metabolic water and CO_2. The two processes are accomplished in a batch process at the base vehicle. Several types of closed CO_2 control systems have been analytically investigated in the past. One of two techniques have been used: thermal regeneration or electrochemical regeneration.

Thermally regenerable systems use metal oxides, metal hydroxides or alkali metal bicarbonates in a reaction with CO_2, to form a carbonate. Initial CO_2 absorption may be accomplished via airflow over solid pellets or by flow past membranes or porous plates which contain the sorbent in aqueous solution. A circulating H_2O solution with a membrane or porous plate reactor may be preferable to a solid pellet system. The reaction is reversed at elevated temperature; thus, with applied heat the CO_2 can be removed and the clean sorbent used again. An inherent problem with this technology are the thermal stresses imposed on the system. As the reactants go toward products, the volume increases. During regeneration the volume decreases. Repeated thermal cycling imposes a design requirement on the reactor.

Reactor design is secondary to the chemistry itself, however. Initial Pathfinder efforts will investigate the materials. Several candidate sorbent materials have been investigated in considerable detail. The drawbacks lie in the efficiency of the reactions, regeneration temperatures, and material stability. The degree of completion of the reaction is affected by the reaction rate, gas diffusion of CO_2 in the airstream, and internal diffusion of the carbonate. Materials must be identified which absorb CO_2 at low temperatures and which are regenerated at temperatures not prohibitively higher. In addition, the material must be stable over many absorption/desorption cycles.

Electrochemically regenerable systems include alkali metal hydroxides and superoxides. Electrical energy is provided during regeneration to drive the metal carbonate breakdown reaction. Some materials require an acid pre-treatment to release the CO_2. A low-voltage regeneration cell with a high conversion rate, a critical element to the success of this technology, remains undemonstrated to date. In spite of this, the probable backpack volume savings gained from the use of this technology justifies further investigation.

For both types of regenerable systems, the selectivity of available membranes must be enhanced. This technology will be pursued under Project Pathfinder. Advances in facilitated membrane transport are relevant and have immediate applications to the portable life support system as well as the base vehicle life support system.

Trace Contaminant and Microbial Control (WBS 1.2.2.4): Trace contaminants within the EVA suit are products of astronaut biological processes. Typical contaminants include: acetone and sulfur dioxide from urine; carbon monoxide, isoprene and methyl alcohol from expired air; and ammonia from perspiration. Microorganisms and microorganism waste products also represent a health hazard. On long-duration missions, the same suit or suit element may be used by several crewmembers. It is important to prevent the transfer of disease from one crewmember to another.

In determining allowable levels of such contaminants, it has been customary in the past to use 10% of the threshhold limit values established by the American Conference of Industrial Hygienists. Odorous substances should be maintained at levels below the odor threshhold concentration. The production rates of these contaminants varies with physical activity level and among individuals. In addition, there are transient peaks, with peak concentrations much greater than the average.

Contaminant control systems for EVA have been investigated extensively and the technology is mature. It is agreed that a system using a biological filter, charcoal absorbent cartridge, and catalytic converter will maintain all contaminant levels below the recommended maximums. Activated charcoal alone may provide sufficient contaminant control. It has been found also that impregnating the bed with a strong base improves efficiency. Additionally, locating the contaminant control system upstream from the humidity control system improves the removal efficiency. The primary work needed is to develop easily maintainable filter technology. Consideration must also be given to cleaning and microbial control throughout the PLSS since this may become a problem in systems used for many hours of EVA.

Immediate efforts in this area are not necessary until other PLSS subsystem concepts are better defined. At that time, a system can be designed to integrate with other components into the portable life support system. With consideration given to PLSS packaging and maintainability an optimum cartridge size can be determined.

Humidity Control (WBS 1.2.2.5.): The function of the humidity control system is to control the humidity of the astronauts' breathing gas.

There are three general methods of water removal. The first involves cooling the gas below its dew point to condense the water vapor. Compression of the gas enhances the process, as do low temperatures. The technology is the same as that used in air-conditioning, although it is complicated by space requirements for low power, weight, and volume. Cooling requirements impose a load on the PLSS heat rejection system. Radiation to a low temperature heat sink, as on the Martian surface, may facilitate water removal by freezeout.

Collecting the water after condensation can be accomplished by one of several means. One device, the cyclone water separator, uses centrifugal force; it requires that the air be compressed for separation to occur effectively. A centrifugal fan is another means of accomplishing this, though it has the reliability and maintainability deficiencies of rotary equipment. A combination of hydrophilic and hydrophobic screens can be used also. Water droplets will pass through the hydrophilic screen only, and gas will pass through the hydrophobic screen. An annular arrangement of this type was used in the Apollo Command Module.

A second method of water removal involves absorption of atmospheric moisture by liquid chemicals in spray chambers or packed columns. This technique is not feasible for zero-g environments due to problems in liquid-gas contacting and water separation.

A simple alternative to these condensation methods is a solid sorbent. The method has been in use in the chemical industry for years and circumvents the thermal and zero-g problems of the previously described methods.

Dessicants can be categorized according to the method by which H_2O is removed from the airstream. Absorbent compounds, as a class, undergo undesirable reactions presenting practical problems in the control of chemical products. Adsorbents attract water molecules through physical forces. From this class, molecular sieves exhibit higher H_2O capacity at low vapor pressures than both silica gel and activated alumina. The dessicant bed size affects the total heat of adsorption, which is a thermal load on the backpack unless the bed is cooled. Energy must be supplied in the regeneration process to restore the adsorbent. The disadvantage in molecular sieves lies here. Because of their higher affinity for water, higher temperatures are required for regeneration.

Future efforts in the humidity control will be concentrated on development of reliable condensing heat exchangers, membrane vapor separation, and regenerable desiccants. As was stated previously, a condensation/separation operation is complicated in a zero-g environment. However, it may be suitable for partial-g operation, as on the Lunar and Martian surfaces. The high maintenance penalty associated with this equipment in the past will not be acceptable for the Pathfinder missions.

2.5.2.3 Description

During the first phase of the Pathfinder Project, efforts will be concentrated on the detailed investigation of promising technologies. Analytical methods and breadboard demonstration units will be pursued to elucidate details of the physical and chemical processes. For example, Charge Distribution Analysis is a powerful new computational tool for determining oxide surface charges. A task will be started to perform an analytical evaluation of oxide doping in an effort to facilitate the modeled scrubbing reaction. Items to be addressed are (1) how CO_2 adsorption and desorption affect the charge distribution, (2) how the growing carbonate layer impedes the reaction, and (3) whether water vapor enhances the reaction. The analytical results obtained from this task in its first two years will be translated into analytically substantiated, doping strategies for candidate CO_2 scrubbers. The doped materials can then be evaluated for adsorption reaction rate and efficiency.

More efficient means of humidity control will also be pursued. Alternates to current techniques are desirable. A preliminary investigation of membrane water vapor separation will be performed. The problem of membrane clogging and subsequent decline in reaction efficiency will be addressed.

2.5.2.4 Schedule

The schedule for the Atmosphere Control Sub-element is illustrated in Figure 2.5.2-1. Concept development programs encompass two phases: a basic research/analysis phase, and a breadboard unit development stage. A subsystem for each proposed mission will be selected and prototypes of the selected subsystems will be fabricated for integration into a total PLSS prototype configuration. Prototype fabrication will begin at or near the end of the first five-year phase.

Figure 2.5.2-1 Schedule
WBS 1.2.2 ATMOSPHERE CONTROL

Project Element	*Fiscal Year* 89	90	91	92	93
• 1.2.2.1 Subsystem Analytical Modeling	//////////	//////////	//////////		
• 1.2.2.2 Oxygen Supply					
- High press. O_2-compression techniques		//////////	//////////	//////////	//////////
- Bottle/regulator concepts			//////////	//////////	
- Subsystem test and evaluation				//////////	//////////
- Air circulation			/////	//////////	/////
• 1.2.2.3 Carbon Dioxide Control					
- Charge distribution analysis of CO_2 adsorbents		//////////	//////////	//////////	
- Enhanced CO_2 adsorbent materials dev.		/////	//////////	//////////	///////
- Regeneration equipment		/////	//////////	//////////	//////////
- Subsystem test and evaluation				/////	//////////
• 1.2.2.4 Trace Contaminant & Microbial Control		//////////	//////////	//////////	
- Subsystem test and evaluation				/////	///////
• 1.2.2.5 Humidity Control					
- Condensing heat exchangers		//////////	//////////	//////////	
- Membrane vapor separation		//////////	//////////	//////////	
- Subsystem modeling		//////////	//////////		
- Subsystem test and evaluation				//////////	//////////
• 1.2.2.6 Subsystem Test					//////////

2.5.2.5 Milestones and Deliverables

See Figure 2.5.2-2.

Figure 2.5.2-2 Major Milestones and Deliverables

WBS 1.2.2 ATMOSPHERE CONTROL

Project Element	*89*	*90*	*91*	*92*	*93*
• PLSS Subsystem Breadboards					
- Zero-g			Δ		
- Lunar				Δ	
- Mars				Δ	
• PLSS Subsystem Selections					
- Zero-g			Δ		
- Lunar				Δ	
- Mars					Δ

2.5.2.6 Resource Allocation

The overall resource distribution is shown in Table 2.5.2-1.

Funding for PLSS atmosphere control research for the next four years (1990-1993) will increase substantially as emphasis shifts from a basic research focus to breadboard demonstration units and prototype development. During the last five years of Pathfinder (1994-1998), funds will be directed toward subsystem and system integration methodologies; thus, funding in WBS 1.2.2 will decline rapidly.

Table 2.5.2-1 Resource Allocation

WBS 1.2.2 ATMOSPHERE CONTROL

	Fiscal Year ($K) 89	90	91	92	93
1.2.2.1 Subsystem Analytical Modeling					
ARC	25	50	0	0	0
JSC	100	50	70	0	0
1.2.2.2 Oxygen Supply					
ARC	0	30	100	100	130
JSC	0	120	160	180	150
1.2.2.3 Carbon Dioxide Control					
ARC	0	150	200	200	100
JSC	0	50	50	50	150
1.2.2.4 Trace Contaminant and Microbial Control					
ARC	0	0	0	0	0
JSC	0	50	100	100	100
1.2.2.5 Humidity Control					
ARC	0	0	0	0	0
JSC	0	100	150	150	0
1.2.2.6 Subsystem Test					
ARC	0	0	0	0	100
JSC	0	0	0	50	100
Total ARC	25	230	300	300	330
Total JSC	100	370	530	530	500
Total for Project Sub-Element	125	600	830	830	830

2.5.3 Monitoring and Control

2.5.3.1 Objectives

The new generation of portable life support systems will be different from its predecessors in many ways. Monitoring and Control (WBS 1.2.3) will provide several benefits to the PLSS that were unachievable with the past systems. Specific objectives for this sub-element are to:

- develop an automated control subsystem for astronaut thermoregulation
- develop automated control subsystems for astronaut ventilation and pressure regulation
- develop new gas sensor technology to support automatic control system operation
- develop a subsystem-integrated supervisory control system including fault detection and diagnosis
- develop a PLSS display/annunciator system to relate system state information to the suited EVA astronaut

These specific objectives will be met by a technical project emphasizing analytical modeling and system integration.

2.5.3.2 Technical Approach

PLSS monitoring and control is a necessary project area for technology development. The suited EVA astronaut depends on the PLSS to maintain a comfortable, natural micro-climate around him/her as he/she routinely ventures out to work in hostile environments. This sub-element will generate equipment and systems to:

- control metabolic heat content to maintain a comfortable body heat content as the real-time requirements change
- monitor oxygen supply, carbon dioxide washout, and appropriate total and partial gas pressures to meet physiological requirements (including those that may change relative to the astronaut's workrate)
- identify potential faults and provide system diagnosis functions
- relay required PLSS-state information to the astronaut at the appropriate time

Current PLSS display and control functions are provided by the Display and Control Module (DCM). The DCM is a chest-mounted unit allowing, among other things, manual control of liquid cooling garment flow and temperature, and providing suit pressure, gauges, switches, and liquid crystal displays of PLSS-state information. A wrist mirror is used to view the dials on the front of the DCM. Although this system of display and control is functional, it is primitive and deserves attention considering the current advances in automation and information technology.

Presently a fixed-rate fan is used to provide gas circulation in the Shuttle EMU. The fan circulates flow for a worst-case situation of maximal metabolic rate and therefore maximal carbon dioxide production. This design is quite inefficient over the mission duration since the maximal metabolic rate is only maintained for a small fraction of the total EVA-mission duration. Even a variable rate fan designed to accommodate a flow which can double or triple at times may not significantly improve efficiency. Studies have indicated that multiple parallel fans, each sized for the appropriate fraction of the total metabolic rate, is a system concept which appears to be best suited to this application.

The PLSS Monitoring and Control sub-element will flow through four distinct phases with the final phase representing a satisfactorily-tested preprototype or breadboard deliverable.

The first and third phases apply only to WBS 1.2.3.2 Automated Control Technology and WBS 1.2.3.3 Display Technology. The first phase is an assessment of PLSS monitoring and control requirements based on mission, human, and environmental considerations. This will include a definition and requirements report. State-of-the-art technology will then be applied to the requirements to develop concepts. In the second phase, the subsystem concepts will be modeled and analytically evaluated in order to measure the effectiveness of the proposed system in meeting the requirements. This work corresponds to that called out in WBS 1.2.3.1 Subsystem Analytical Modeling. A quantitative report will be the deliverable of the second phase showing the trade-off (gains and losses) associated with the new concept. The third phase will be done under WBS 1.2.3.2 and WBS 1.2.3.3 and involves fabrication and development of a system/hardware technology demonstrator. The final phase corresponds to the work in WBS 1.2.3.4 Subsystem Tests. The demonstrator unit will be evaluated in a simulated EVA-reference mission scenario. A technology readiness report will document the results of the evaluation.

2.5.3.3 Description

Monitoring and control functions of the PLSS will be much more significant and necessary for the new generation of automatically-controlled systems. Oxygen supply, carbon dioxide removal, and thermal control are functions of the PLSS which are dependent upon the metabolism and therefore workrate of the astronaut. Good design principles require life support designers to provide adequate life support for a range of workrates without overdesign of the system components. In the interest of system power efficiency, it would be ideal to be able to sense a change in the work rate and then instantaneously adjust oxygen supply, carbon dioxide removal (possibly by adjusting air flow rate), and thermal control via air and liquid cooling garment water flow rate and temperature to adequate limits. The use of diagnostics as a method of fault detection and error-handling will make the system much safer and more efficient. Although the control system will be automatic, visual display or audio annunciator techniques will relate PLSS-state information as required.

Analytical modeling of subsystem monitoring and controlling functions must be done initially to quantitatively determine the system benefits of automatic control. First, a study must be done to determine the mass, volume, and electrical power savings using an automatically controlled system. Experimentation may be done as necessary to obtain the physiological parameters that will be used as sensed input for the control system. A control algorithm will be developed from statistical methods and sensitivity analyses. A computer model of each subsystem (thermal and atmospheric) will then be developed within the framework of a supervisory control system. The supervisory control system will be similar to a computer operating system. It will prioritize simultaneous requests from the subsystems, provide error detection and fault diagnosis, and allow manual override of subsystem control.

Once the supervisory control system and subsystems are modeled and integrated, analytical-system tests will be done for verification before breadboard development. Physiological data and a series of what-if scenarios can be entered as input in order to observe the system control and monitoring ability. An analytical trade-off study will also be done in order to evaluate the utility of the programmable, variable-pressure regulator to allow reduction of suit pressure after initial bends limitations have been met.

New EVA simulation exercises will be developed to allow variable workrate experiments to collect data for the metabolic responses of the subject. The data will be reduced and analyzed to find patterns to associate a given oxygen consumption, carbon dioxide production, and heat production with metabolic rate. A feedback control algorithm will be developed and modeled on a personal computer. Eventually a microprocessor will be programmed to control the oxygen supply, carbon dioxide removal, and heat removal based on sensed changes in the metabolic rate.

The new generation PLSS will be different from its predecessors in many ways, but one of the more obvious differences will be an increased efficiency. Better controls will be the key. Specific examples are:

Higher accuracy of the controls brought about by instituting the new EVA simulation exercises in the controller development program. Previously, controller development was based on metabolic responses to treadmill exercises. However, treadmill running elicits a different pattern of responses. The previously mentioned lab exercises will be specifically developed to more accurately represent orbital/Lunar/planetary EVA work. Therefore, the controller developed from the exercise responses will be more accurate in predicting and providing for the physiological needs of the EVA.

Faster response time of the controller through the use of oxygen consumption, CO_2 production, and total evaporated water as an additional indicator of metabolic rate. Typically, only oxygen consumption and carbon dioxide production have been used to determine the metabolic rate and thermal state of the working astronaut. The proposed solution would be to include evaporative water as an additional indicator of the thermal comfort.

Adaptive control conditions will allow for an intelligent controller response. Commonly, a controller responds the same way to the same input. However, this concept would require the controller to predict the direction of the controlled parameter and then control the parameter relative to the direction it is headed. For example, an astronaut's body heat storage may be 300 Btu (which is uncomfortably hot for the astronaut). If the previously calculated body heat storage values reveal an increasing trend, then the controller may recommend a relatively large drop in liquid cooling garment water temperature. If the previous values show a decreasing trend, the liquid cooling garment water temperature may not be decreased as much. Therefore, the controller adapts its response to the trend in the controlled parameter.

Decreased electrical power consumption will be the result of better controls. Currently, the ventilation fan is the largest power sink of the PLSS. One reason for this is that the fan is not variable speed and therefore it must be sized for the worst-case situation of a maximal metabolic rate. Feedback control will allow for instantaneously activating/deactivating any of a distribution of parallel fans for current metabolic requirements, thereby conserving energy while the metabolic rate and carbon dioxide production are below the maximum.

Better controls can be enhanced by an improvement in automatic multiple-gas sensing technology. Currently only one gas is measured within the Extravehicular Mobility Unit (EMU). Carbon dioxide is monitored by a gas sensor with many undesirable features including large volume, slow response time, and short operational life. A new gas sensor should be developed for monitoring carbon dioxide, oxygen, nitrogen, and water vapor. The improved technology would allow development of a miniature, low-power, fast-response gas sensor for use with the PLSS automatic control system.

Because future PLSS will be automatically controlled, new requirements exist for PLSS-state information display. Requirements for display of the various PLSS subsystems will be addressed through an analytical study.

The information technology boom provides us with new display and control techniques, allowing a more elegant solution to applications such as the automatic diagnosis of malfunctions and faults. Display and annunciator technology can also be developed so that activation occurs only on command or that activation occurs when the system determines that the information is useful to the astronaut. This type of display/annunciator system can be found in current automobile dashboard monitoring systems describing state information. Some of the audio signals are low battery voltage, low fuel or oil levels, and reminders for the safety of the occupants indicating unlatched safety belts and doors, and keys left in the ignition. This option allows the astronaut to be unencumbered by dials, gauges, and screens relating PLSS-state information. However, when the astronaut wants the information (for peace of mind or time-critical emergencies), it would be presented as required.

When breadboard development has been completed, manned testing in a simulated EVA mission may be done in order to assess the utility and communication efficiency of the system. Physiological experiments will be done as well to verify the adequacy of thermal and atmospheric control.

2.5.3.4 Schedule

See Figure 2.5.3-1.

Figure 2.5.3-1 Schedule

WBS 1.2.3 MONITORING AND CONTROL

Project Element	*Fiscal Year* 89	90	91	92	93
• 1.2.3.1 Subsystem Analytical Modeling		//////////	//////////	//////////	
• 1.2.3.2 Automated Control Technology					
- Experimentation	//////////	//////////	//////////		
- Breadboard development		//////////	//////////	//////////	//////////
- Sensor technology concepts	/////	//////////	//////		
- Sensor hardware development			/////	//////////	//////////
- Pressure regulation trade study		//////////			
• 1.2.3.3 Display Technology					
- Requirements definition		//////////			
- Concepts study			//////////	//////////	
- Breadboard development				//////////	//////////
• 1.2.3.4 Subsystem Test					//////////////(FY94)

2.5.3.5 Milestones and Deliverables

See Figure 2.5.3-2.

Figure 2.5.3-2 Major Milestones and Deliverables

WBS 1.2.3 MONITORING AND CONTROL

Project Element	*Fiscal Year* 89	90	91	92	93
• Automatic control breadboard					
- Zero-g		Δ			
- Lunar			Δ		
- Mars					Δ
• Display breadboard					Δ

2.5.3.6 Resource Allocation

The resource allocation is provided in Table 2.5.3-1.

Table 2.5.3-1 Resource Allocation

WBS 1.2.3 MONITORING AND CONTROL

	Fiscal Year ($K) 89	90	91	92	93
1.2.3.1 Subsystem Analytical Modeling					
ARC	0	50	100	100	0
JSC	0	0	0	0	0
1.2.3.2 Automated Control Technology					
ARC	50	175	225	225	175
JSC	0	125	225	225	75
1.2.3.3 Display Technology					
ARC	0	50	170	170	300
JSC	0	0	0	0	0
1.2.3.4 Subsystem Test					
ARC	0	0	0	0	120
JSC	0	0	0	0	0
Total ARC	50	275	495	495	595
Total JSC	0	125	225	225	75
Total for Project Sub-Element	50	400	720	720	670

2.5.4 System Integration

2.5.4.1 Objectives

The objective of the System Integration (WBS 1.2.4) sub-element is to coordinate the efforts in WBS 1.2.1. through WBS 1.2.3 to provide an integrated systems approach toward the development of portable life support systems. Specific responsibilities include:

- definition of requirements for packaging, testability, maintainability, reliability, and diagnostics; and design of test, diagnostic, and servicing equipment
- compilation of a logistics/maintenance database on PLSS components and subsystems for use in simulation analyses in WBS 1.1.3.3. Perform logistics/maintenance simulation analyses for portable life support subsystems and system configurations.
- analysis of portable life support subsystem configurations with respect to volume, weight, power, and performance
- design of an integrated PLSS configuration, including design of subsystem interfaces and PLSS packaging
- verification and validation of systems

2.5.4.2 Technical Approach

Future long-duration space missions will require a degree of autonomy from ground-based support and logistics systems much greater than that for space missions of the past. In order to provide extravehicular activity as a useful mission resources these missions will require portable life support systems which are extremely reliable, supportable, and user-friendly. Special emphasis must be placed on safety, economics, automation, logistics management, and development of systems analysis, synthesis, and design techniques which will lead to systems concepts and designs that satisfy mission requirements.

In past programs, integration issues have played a minor role in the early stages of component and subsystem design. The aspects of supportability, testability, and maintainability have influenced designs, for the most part, in a retrospective manner. In this case, resulting operational and maintenance costs, i.e. life-cycle costs, can be prohibitive. Establishment of test, diagnostic, and support equipment requirements must proceed concurrently with subsystem development in order to identify any commonalty of requirements among the subsystems. Possible common support and test equipment can then be determined and designed.

2.5.4.3 Description

Two tasks will be funded in FY89 for the PLSS System Integration (WBS 1.2.4) sub-element. This is because many of the design criteria for PLSS subsystems will be a result of investigations into mission requirements or human requirements. These requirements will be determined in the first three years of the project and solidified with the establishment of a design reference mission in 1993. Once a DRM has been defined, an inter-center working group will be assigned the responsibility of coordination with the various PLSS subsystem technology projects to achieve the objectives of this sub-element. The first goal is the compilation and maintenance of a logistics/maintenance database on PLSS components and subsystems for use in the simulations developed in WBS 1.1.3.3. Members of the Inter-Center Working Group may be drawn from the PLSS subsystem design engineers, NASA program management, logistics managers, and others. The database will include information on required inventory/resupply, diagnostics and test equipment, and servicing equipment procedures. These responsibilities fall within the scope of System Integration Requirements (WBS 1.2.4.).

Once the subsystem technologies have been developed to the breadboard level, trade-off studies among the candidate subsystems will be performed. Analytical subsystem models developed in WBS elements 1.2.1, 1.2.2, and 1.2.3.1 will be adapted and used for this purpose to the extent possible. These trade-off studies will aid in the selection of subsystem(s) for mission-specific PLSS configurations. A significant factor in the selection of subsystems will be subsystem regeneration methods. The detailed design of regeneration equipment falls into the broad category of support equipment. Certain subsystems may have a significant launch (weight) penalty due to regeneration equipment. This factor must be considered in subsystem selection as well as subsystem weight and performances.

The configurations can then be evaluated (WBS 1.2.4.1) with respect to volume, weight, power, and performance for the intended missions. Mock-ups will be fabricated to assist in the determination of packaging envelopes and subsystem interface details before a prototype integrated PLSS is fabricated and tested. The integrated PLSS demonstrator system(s) operation will then be verified.

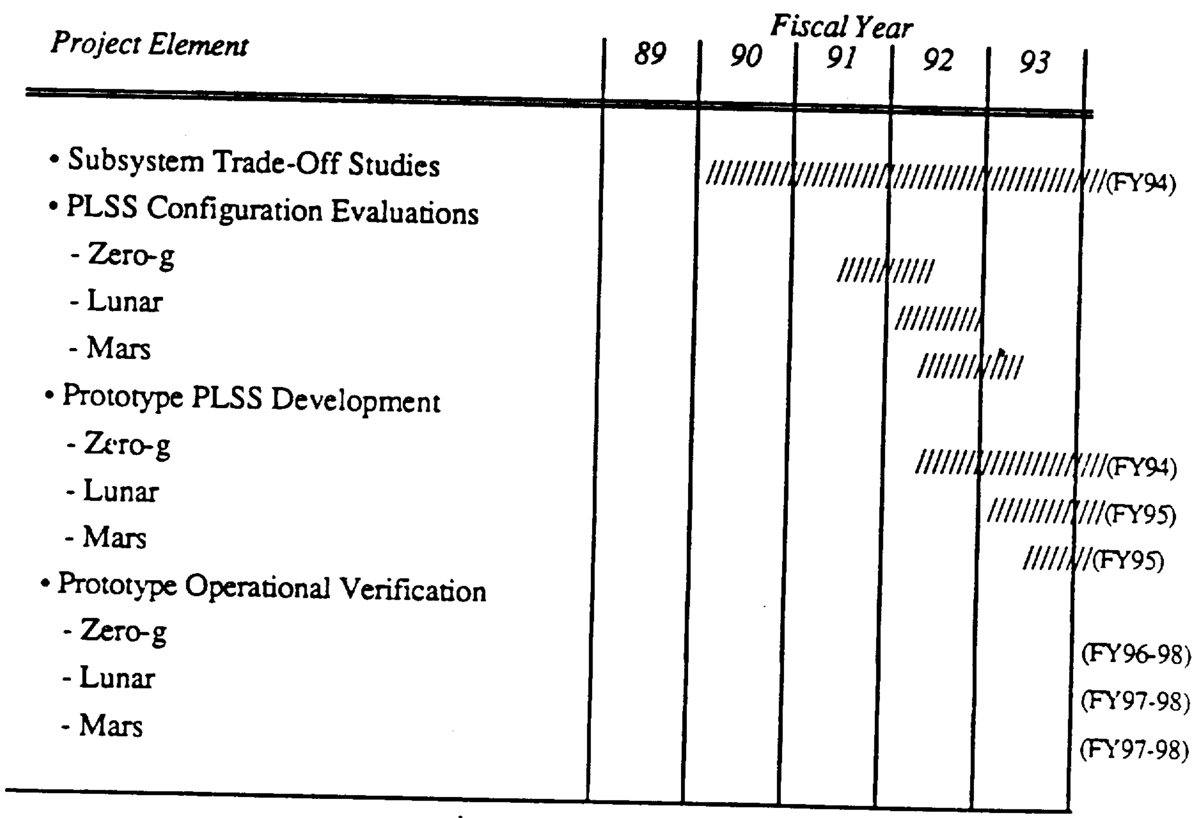
The phasing of these tasks is common to orbital, Lunar, and Martian PLSS but absolute timing will vary. It is expected that integrated technologies developed for the orbital PLSS of the Shuttle and Space Station will provide a firm technology base for the zero-g PLSS development under Pathfinder. We know a considerable amount about the Lunar surface, having been there numerous times during the Apollo program, but considerable technological advances have been made since that time. An allowance must be made for adaptation of these technologies to the Lunar environment. We have never had a Lunar mission of the proposed Pathfinder durations; both old and new technologies for Lunar surface application must be examined in light of Pathfinder mission requirements. The Martian planetary mission holds the most unknowns. Until environmental and mission parameters are incorporated into EVA equipment design guidelines, the PLSS subsystem detailed designs cannot proceed. It is expected that PLSS technology will mature sequentially for zero-g, Lunar, and Martian Pathfinder missions and this is reflected in the system integration schedule for WBS 1.2.4.

2.5.4.4 Schedule

See Figure 2.5.4-1.

Figure 2.5.4-1 Schedule

WBS 1.2.4 SYSTEM INTEGRATION



2.5.4.5 Milestones and Deliverables

See Figure 2.5.4-2.

Figure 2.5.4-2 Major Milestones and Deliverables

WBS 1.2.4 SYSTEM INTEGRATION

Project Element	*Fiscal Year* 89	90	91	92	93	
• PLSS susbystem selection						
- Zero-g			Δ			
- Lunar				Δ		
- Mars				Δ		
• Integrated PLSS concept mockup						
- Zero-g				Δ		
- Lunar				Δ		
- Mars					Δ	
• Integrated PLSS detailed design review						
- Zero-g					Δ	
- Lunar					Δ	
- Mars						Δ (FY94)
• Prototype fabrication complete						
- Zero-g						Δ (FY94)
- Lunar						Δ (FY95)
- Mars						Δ (FY95)

2.5.4.6 Resource Allocation

As shown in Table 2.5.4-1, $100K has been allotted to this sub-element in FY90 in order for a low level of effort to be expended on an investigation of PLSS requirements packaging concepts. The most efficient exterior envelope will be defined to the extent possible. This sub-element will also explore the aspects of modularity, ease and efficiency of maintenance, and future retro-fit in order to integrate the latest technological advances in PLSS subsystems. It will continue at a low level in the near future until mission-specific subsystems have been chosen and need to be integrated into an efficient package.

Table 2.5.4-1 Resource Allocation

WBS 1.2.4 SYSTEM INTEGRATION

	Fiscal Year ($K)				
	89	*90*	*91*	*92*	*93*
WBS 1.2.4.1 Requirements					
ARC	0	25	0	0	0
JSC	0	25	0	0	0
WBS 1.2.4.2 Analysis					
ARC	0	25	25	0	0
JSC	0	25	25	0	0
WBS 1.2.4.3 Support Equipment & Interfaces					
ARC	0	0	0	0	50
JSC	0	0		50	50
Total ARC	0	50	25	0	50
Total JSC	0	50	25	50	50
Total for Project Sub-Element	0	100	50	50	100

2.6 EVA SUITS AND EQUIPMENT

2.6.1 Pressure Suit Technology

2.6.1.1 Objectives

EVA has been identified as a major element of the Pathfinder Program. Historically, the approach to of EVA has been one of extreme conservatism in that EVA was (and is) either planned as a short-duration activity or used for contingency operations of minimal duration. The EVA suit was subsequently designed to meet these requirements but with the luxury of ample time between missions for refurbishment, resizing, routine maintenance, and component changeout.

Although space suits and EVA systems have been used in space and on the Lunar surface, advancements in suit technology must be made to insure that a technology base for a rugged, highly reliable, mobile, and easily serviced EVA suit be available to meet the operational requirements for extended Lunar and planetary missions. The candidate missions identified by the Office of Exploration contain elements of commonality; however, significant differences exist in terms of gravity, atmosphere, temperature, and surface conditions that will be encountered by the EVA system.

The objectives of this effort are to develop suit technologies which will meet the environmental requirements for extraterrestrial EVA operations. Of prime importance are comfort, environmental protection, and work efficiency which will allow for maximum EVA productivity. Of equal importance is to develop, expand, and exploit the technology base within NASA, industry, and the university system so that a more competitive environment for future EVA hardware procurements can be assured.

2.6.1.2 Technical Approach

Past developments have demonstrated a family of suit joints and components which will meet the requirements for a highly mobile suit operating within a range of internal pressures up to 1 atm, precluding the requirement to expend large resources to develop new basic concepts to improve suit function. Emphasis will be focused on design and development issues unique to extraterrestrial surface environments and to enhance the manufacturability, reliability, maintainability, and weight reduction of the suit components.

In the past, the single most unpredictable element of the development of suit joints and structures has been the manufacturing techniques and materials employed. This, in part, is the result of the somewhat specialized capabilities of the "suit industry". Other industries have and will develop technologies which are relevant to space suit construction and will serve as an additional source for the technology base for this effort. Since a broad knowledge base exists within NASA on the functional aspects of suit technology, this expertise will be exploited to the fullest extent to transfer this knowledge to industry such that during the development phases of this project industries with unique and applicable materials and fabrication capabilities will be encouraged to participate.

This philosophy will be followed throughout the various phases of this development project. Processes and materials will be reviewed as to their applicability to the requirements previously set forth. Issues such as design changes required to adjust suit performance to accommodate, for example, differences in gravity (i.e. suit more self-supporting for partial-g operations) will be thoroughly defined and implemented. Weight reduction and environmental protection (i.e. dust, abrasion, temperature, radiation) are critical design issues requiring unique solutions.

From this database, candidate structures, components, and joint concepts will be fabricated, tested, and evaluated. The most promising concepts will be utilized to form a matrix of suit configurations that will most optimally meet the specific mission requirements. From this selection process, suit technology demonstrators will be fabricated for extensive testing and evaluation. Subsequent upgrades will be incorporated and demonstrated prior to commitment to a particular design for a specified mission scenario.

The Pressure Suit Technology (WBS 1.3.1) sub-element under EVA Suits and Equipment (WBS 1.3) is divided into four task areas:

Suit Materials and Structures (WBS 1.3.1.1): This task area addresses the materials, processes, and structural issues related to the pressure vessel elements of the suit, thermal and micro-meteoroid garment (TMG), thermal coatings, boots, helmet, and extravehicular visor assembly (EVVA).

Suit Components and Mobility Elements (WBS 1.3.1.2): This task area interrelates with WBS 1.3.1.1. Mobility elements will be fabricated and tested based on the materials and fabrication processes selected for development. Component development includes design and development of suit closures, dust seals, sealed bearing assemblies, connector covers, helmet/EVVA assembly, and EVA "overboot" for abrasion and thermal control.

Suit Configurations (WBS 1.3.1.3): From the matrix of structural options, materials, processes, and mobility joints, suit configuration concepts will be established which best meet the requirements of selected missions.

Suit Technology Demonstrator (WBS 1.3.1.4): This task area produces a suit technology demonstrator for extensive testing and evaluation.

A discussion on the state-of-the-art and the rationale for the course of development for each WBS follows.

Suit Materials and Structures (WBS 1.3.1.1): In discussing the state-of-the-art of suit materials and structures, a high level of technology exists for implementation that has not been utilized in past EVA flight hardware. All flight suits have been fabricated utilizing bonded bladder and stitched construction techniques that are typical of the garment industry. These suits were classified as "soft suits". A family of prototype space suits was developed during the 1960's and 70's that demonstrated more repeatable laminate fabric construction techniques and utilized composite and metallic structures extensively in the suit structure. These suits were classified as hard and hybrid suits. Functionally all of these technologies performed well and serve as a technology base to build on. In the development of these technologies, however, a significant amount of art was required in the fabrication process.

A number of technologies have since been developed that have considerable potential for implementation. Both ARC and JSC have supported development efforts in fabric technologies. These include heat-shrinkable seamless fabric tube construction methods, tapered seamless fabric tube weaving techniques, triaxial woven fabrics, laminate coating processes, and blow-molding forming methods. The most recent developments, ARC's AX-5 and JSC's ZPS Mk III, demonstrated for the first time construction methods utilizing numerical-controlled milling technology which is widely used in other industries. The significant point in selecting this construction method is that the efforts can be competitively bid since many companies have the required fabrication expertise. Typically, the hard structures utilized in the past were hand-layup, composite structures requiring a large investment in hard tooling.

With these data, the technologies that have been shown to offer the most promise for the development and implementation in the suit structures are seamless fabric tube weaving methods, heat shrinking/forming processes, die-forming, blow-molding, coatings for fabrics, and casting processes for hard materials. Minimal technology risks are foreseen in this development. Attention will be given to radiation, abrasion, and impact protection properties of the materials. The ultimate goal is to ensure that suit construction becomes a science rather than an art.

Suit Components and Mobility Elements (WBS 1.3.1.2): Those elements of the suit which are identified as suit components are the EVVA/helmet assembly, torso closures, TMG, LCVG (liquid coolant ventilation garment), and boot. The mobility elements are the anatomical flexure joints located at the shoulder, elbow, waist, hip, knee, and ankle, and the associated sealed bearings required for mobility function.

A history of development is associated with each element identified. In addressing the current state-of-the-art of the various suit components, minimal technology development will be required in selecting suitable design configurations for the suit closures and LCVG. Conversely, a significant level of effort must be expended on the EVVA/helmet assembly, TMG, and boot.

The EVVA/helmet assembly as currently designed, will be highly susceptible to damage due to the expected severe problem of dust on the Lunar and Mars surfaces. In addition, with the possible incorporation of heads-up display technology, unique designs must evolve which allow for hardware interface compatibility and control of light transmission through the sun visor.

As identified previously, protecting the suit structure from the dust and thermal environment is of major importance. Advancements in the design and materials selection for the TMG and boots are critical to the utility of the EVA system. Improvements in overall structural abrasion and puncture resistance, accompanied with the additional thermal protection requirements, will be a major effort in the suit component development.

In addressing the mobility elements of the suit, a family of acceptable suit mobility joints have been developed in the past. The major thrust of this task area of the WBS is to develop proof-of-concept joints for evaluation and test utilizing technologies developed under Suit Materials and Structures (WBS 1.3.1.1). The generic joint technologies that will be fabricated are rolling convolute, toroidal, multiple bearing, and tucked fabric (flat pattern). Variations of these technologies can be adapted to all joint elements of the suit. In addition, since all suit configurations require the use of rotary sealed bearings, special emphasis will be placed on developing a sealed bearing configuration that is "insensitive" to the environmental contaminants expected on extraterrestrial surfaces. An overall performance assessment will be made of the candidate technologies and will serve as the database for Suit Configurations (WBS 1.3.1.3).

Suit Configurations (WBS 1.3.1.3): From the results of WBS 1.3.1.1 and 1.3.1.2, a matrix of suit configurations will be established which will best meet the requirements of selected missions. Where possible and to avoid unnecessary budget requirements, retrofits will be made to existing flight and prototype suit (AX-5 and ZPS) testbeds to assess the performance of the various suit components and mobility systems. This testbed approaches will provide an additional data point for suit configuration selection.

Suit Technology Demonstrator (WBS 1.3.1.4): Using the results of the preceding WBS elements, a suit demonstrator/demonstrators will be fabricated for extensive testing and evaluation. It is not expected that the mobility joint elements of a Lunar suit would be significantly different from those of a Mars suit. However, the environmental protective features of the suit might be quite different, resulting in the necessity to build more than one proof-of-concept suit demonstrator for different mission scenarios.

2.6.1.3 Description

The specific work to be accomplished in each sub-element of the WBS will be discussed and its relationship to technology developments required for an orderly development schedule. Both near- (FY89) and far-term technology thrusts are presented as follows:

Suit Materials and Structures (WBS 1.3.1.1): Major emphasis (FY89 start) will be placed on fabrication techniques, processes, and associated materials for both the mobility joints and structural elements of the suit. Two tasks submitted address these technologies: Space Suit Materials and Processes (ARC) and Suit Materials and Structures (JSC). A four year effort is proposed for this WBS element.

The goal of the ARC effort is to develop blow-molding as a process for mobility joint manufacturing. The process is well defined and universally used in industry with a large family of available polymeric materials for development. This technology combined with heat-shrinkable tubular fabric technology will be investigated as a candidate fabrication method for the suit mobility joints requiring both fabric laminate construction and hard element structures.

Emphasis of the JSC effort is to develop materials and methods for providing adequate environmental protection against dust, meteoroids, thermal conditions, radiation exposure, and abrasion resistance. Near-term emphasis will be placed on development of a non-dust collecting TMG material, anti-scratch helmet/EVVA coatings, and improved EVA "overboot" for abrasion/thermal protection.

Suit Components and Mobility Elements (WBS 1.3.1.2): This will be a FY90 start (refer to the Objectives and Technical Approach sections).

Suit Configurations (WBS 1.3.1.3): This will be a FY91 start (refer to Objectives and Technical Approach sections).

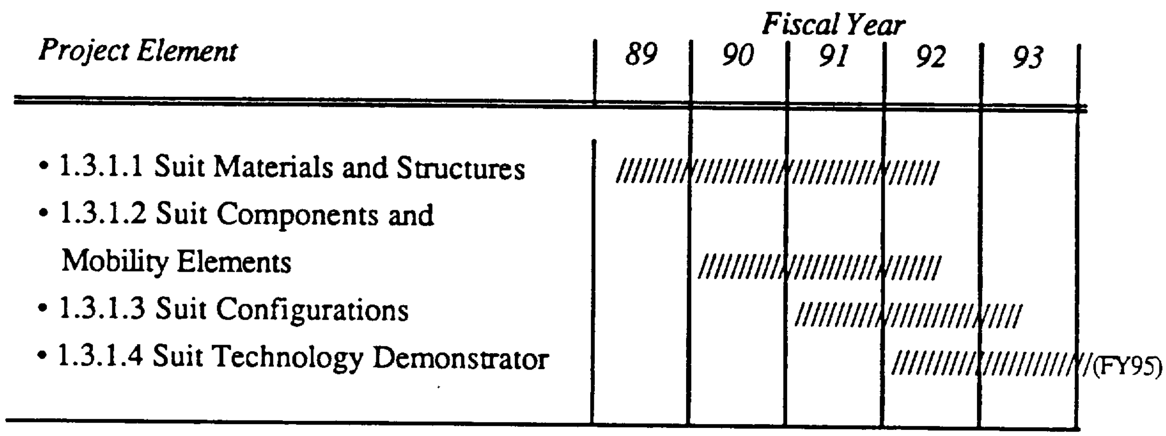
Suit Technology Demonstrator (WBS 1.3.1.4): This will be a FY92 start (refer to the Objectives and Technical Approach sections).

2.6.1.4 Schedule

See Figure 2.6.1-1.

Figure 2.6.1-1 Schedule

WBS 1.3.1 PRESSURE SUIT TECHNOLOGY



2.6.1.5 Milestones and Deliverables

See Figure 2.6.1 - 2

Figure 2.6.1 - 2 Major Milestones and Deliverables
WBS 1.3.1 PRESSURE SUIT TECHNOLOGY

Project Element	*89*	*90*	*91*	*92*	*93*	
• 1.3.1.1 Suit Materials and Structures						
- Blow-molding proof-of-concept		Δ				
- Fabric/bladder integration			Δ			
- EVVA/helmet coatings				Δ		
- TMG materials selection			Δ			
- Boot material design selection			Δ			
- Light weight hard structures selection			Δ			
• 1.3.1.2 Suit Components and Mobility Elements						
- Mobility joint			Δ			
- Fabrication test prototypes				Δ		
- Rotary sealed bearing				Δ		
- TMG materials/structure				Δ		
- Sealed bearing design			Δ			
- Boot fabrication/evaluation				Δ		
- EVVA/helmet fabrication/evaluation				Δ		
• 1.3.1.3 Suit Configurations						
- Configuration options			Δ			
- Configuration selections				Δ		
• 1.3.1.4 Suit Technology Demonstrator						Δ(FY95)

Fiscal Year (column heading over 89–93)

2.6.1.6 Resource Allocations

For FY89 the budget allocations are \$100K (ARC), \$100K (JSC), and \$0K (LaRC). This allocation serves as a starting point to support initial efforts in the Suit Materials and Structures effort. As shown in Table 2.6.1-1, subsequent allocations will be distributed based upon available funds and priorities established within the defined goals of this WBS.

Table 2.6.1-1 Resource Allocation

WBS 1.3.1 PRESSURE SUIT TECHNOLOGY

	Fiscal Year ($K)				
	89	*90*	*91*	*92*	*93*
1.3.1.1 Suit Materials and Structures					
ARC	100	175	150	100	50
JSC	100	175	150	100	50
LaRC	0	50	75	0	0
Total	200	400	375	200	100
1.3.1.2 Suit Components and Mobility Elements					
ARC	0	200	300	200	100
JSC	0	200	300	250	100
LaRC	0	0	0	0	0
Total	0	400	600	450	200
1.3.1.3 Suit Configurations					
ARC	0	0	75	200	50
JSC	0	0	150	300	50
LaRC	0	0	0	0	0
Total	0	0	225	500	100
1.3.1.4 Suit Technology Demonstrator					
ARC	0	0	0	350	900
JSC	0	0	0	350	900
LaRC	0	0	0	0	0
Total	0	0	0	700	1,800
Total ARC	100	375	525	850	1,100
Total JSC	100	375	600	1,000	1,100
Total LaRC	0	50	75	0	0
Total for Project Sub-Element	200	800	1,200	1,850	2,200

2.6.2 Glove and End-Effector Technology

2.6.2.1 Objectives

Although space suit technology has advanced to a high degree of development, one element of the EVA system that would benefit from major advancements is glove and end-effector technology. Great improvements must be made to allow for more efficient use of the hands in performing EVA tasks. Classically, pressure gloves have been used throughout the history of EVA systems. Production of space suit gloves which provide a high degree of tactility, dexterity, comfort, and reliability while employing easily repeatable, low-cost manufacturing techniques has not been achieved to date. As an added EVA enhancement capability, end-effector technologies have not been explored in depth as to their utility in performing EVA tasks.

The objectives of the Glove and End-Effector Technology (WBS 1.3.2) sub-element are to:

- develop glove technologies which provide the levels of comfort, protection, mobility, and work efficiency to meet various long-term planetary surface mission and human performance requirements
- develop manufacturing techniques, processes, and suitable materials to improve reproducibility and reliability at reduced cost
- develop end-effector technologies that will enhance EVA productivity

Industries with unique capabilities will be encouraged to participate in this effort in order to assure a competitive environment for future procurements.

2.6.2.2 Technical Approach

Gloves (WBS 1.3.2.1): The Shuttle EMU glove demonstrates the state-of-the-art in flight glove design and is a product of evolutionary development. The mobility joints are of tucked-fabric, flat-pattern, bladder construction. A Thermal Micro-meteoroid Garment (TMG) outer structure has a multiplicity of material layers of varying cross section to optimize hand mobility, abrasion resistance, and to provide thermal protection.

With the requirement for higher suit pressures, JSC and ARC have been developing advanced glove technology. A hard glove utilizing metal bellows and composite structures was developed by ARC with marginal success in improving glove function. Anticipated astronaut reluctance to accept a technology that severely compromised tactile feedback resulted in abandonment of any further development of an all-hard structure glove. Two parallel glove developments supported by JSC have resulted in improving the performance of gloves, operating at higher pressures, to a level of "meets or exceeds" the current low-pressure Shuttle glove design. However, tactility has been compromised in the palm area of the glove due to the necessity of incorporating a gimballed first metacarpal joint to enhance finger mobility at the higher pressures. In addition, the fabrication technology used is not consistently repeatable.

The evolutionary development of glove technology has been one of "cut, fit, and try". It is expected that a large degree of this development philosophy will still be necessary in this effort, thus creating a high technology risk development program.

The technical approach for developing glove technology is to maintain and support complementary glove development efforts at ARC and JSC. In addition, a recent proof-of-concept demonstration utilizing blow-molding technology as a means of glove finger fabrication will be pursued by ARC to determine its application to total glove development and fabrication.

End-Effectors (WBS 1.3.2.2): Despite longstanding industrial experience with human-powered end-effectors in such areas as radioactive materials handling and undersea hard-suit diving, there are perceived disadvantages in utilizing end-effector technologies for EVA as compared to gloves. In part, such perceptions are a product of inexperience and the lack of "hands-on" exposure to the technology potential. The astronaut has not previously been required to operate such devices and does not know the capabilities and limitations of end-effectors as thoroughly as those of gloves.

The technical approach for developing end-effector technologies which will complement EVA productivity is first to fabricate existing suit-compatible end-effector designs so that an objective, quantitative comparison between end-effector and glove performance can be assessed. Second, the physical existence of these demonstrators will allow "hands-on" exposure for the astronauts, whereby their valuable input can be used to direct the technological requirements and developments of end-effector features such as force amplification, compliance, and tactile feedback.

2.6.2.3 Description

The specific work to be done in FY90 for each task area of WBS 1.3.2 is as follows:

Gloves (WBS 1.3.2.1):

- Initial development effort to demonstrate the blow-molding process as a viable fabrication technique for glove construction.

- Continue to support ongoing glove development at JSC with emphasis on meeting the environmental requirements for extraterrestrial EVA operations.

End-Effectors (WBS 1.3.2.2):

- Fabricate end-effector demonstrators for evaluation and test so that a database can be established for further development.

- Initiate tactile feedback sensor development that will be compatible with end-effector demonstrators.

2.6.2.4 Schedule

See Figure 2.6.2-1.

Figure 2.6.2-1 Schedule

WBS 1.3.2 GLOVE AND END-EFFECTOR TECHNOLOGY

Project Element	*Fiscal Year* 89	90	91	92	93
• 1.3.2.1 Gloves					
- Proof-of-concept gloves		//////////	//////////	//////////	
• 1.3.2.2 End-effectors					
- End-effector demonstrators		//////////	//////////	//////////	//////////

2.6.2.5 Milestones and Deliverables

See Figure 2.6.2-2.

Figure 2.6.2-2 Major Milestones and Deliverables

WBS 1.3.2 GLOVE AND END-EFFECTOR TECHNOLOGY

Project Element	*Fiscal Year* 89	90	91	92	93
• 1.3.2.1 Gloves					
- Blow-molding proof-of-concept				Δ	
- Prototype glove utilizing blow-molding					Δ
- Environmental protective technology demonstration					Δ
• 1.3.2.2 End-Effectors					
- Fabricate end-effector demonstrators				Δ	
- Tactile feedback sensor development				Δ	

2.6.2.6 Resource Allocation

For FY90 the budget allocations are as follows:

Gloves		End-Effectors	
ARC	$175K	ARC	$175K
JSC	$175K	JSC	$75K

This allocation serves as a starting point to support initial efforts in the Glove and End-Effector WBS. As shown in Table 2.6.2-1, subsequent allocations will be distributed based upon available funds and priorities established within the defined goals of the WBS.

Table 2.6.2-1 Resource Allocation

WBS 1.3.2 GLOVE AND END-EFFECTOR TECHNOLOGY

	Fiscal Year ($K)				
	89	*90*	*91*	*92*	*93*
WBS 1.3.2.1 Gloves					
ARC	0	175	150	175	200
JSC	0	175	150	175	200
WBS 1.3.2.2 End-Effectors					
ARC	0	175	150	100	300
JSC	0	75	150	100	100
Total ARC	0	350	300	275	500
Total JSC	0	250	300	275	300
Total for Project Sub-Element	0	600	600	550	800

2.6.3 EVA Ancillary Equipment

2.6.3.1 Objectives

Successful EVA depends heavily on the work capacity of the crewmember. EVA Ancillary Equipment (WBS 1.3.3) encompasses specialized systems and equipment designed to aid the EVA crewmembers in the performance of their tasks. Specific objectives for the current program are to:

- replace cuff-checklist with an interactive graphics and text display system representing state-of-the-art communications technology
- develop new EVA mobility enhancement systems which will be used to increase the crewmember's mobility over the planetary/Lunar terrain. System options may include a modification feature that allows cargo of a moderate size to be carried.
- develop a set of multi-purpose EVA tools and toolbox for construction, maintenance, and assembly applications
- develop a mobile tool caddy and tool set for prospecting, exploring, and sampling the planetary/Lunar surfaces
- develop communication and navigation aids to support routine astronaut exploration activities
- develop new systems for supervisory control of robotic assistants by a suited EVA astronaut

These specific objectives will be met by a well planned, cohesive, technical program to develop equipment to aid the crewmembers during EVA.

2.6.3.2 Technical Approach

EVA Ancillary Equipment is a necessary program area for technology development. For a scenario in which a suited astronaut exits the airlock on a planetary/Lunar surface to begin work for the EVA mission, this program plan will generate equipment and systems to provide:

- work information as necessary for completion of EVA tasks
- communications and controls for supervising robotic assistants at the EVA worksite
- effective tools for completing the work assignment
- studies of modes of transportation and navigation to get to the location where work or scientific observation will begin

Currently the ancillary equipment provided for the EVA astronaut is intended for use in a zero-g environment. The manned-maneuvering unit (MMU) and body/foot restraints would become ineffectual on planetary/Lunar (earth) surfaces. Contrary to the purpose of restraints, body supports may be necessary for doing work in a standing position for long durations on the surface of Mars. EVAs on the Martian moon surface as well as any orbital or transitory EVA will require safety tethers for crew and equipment.

The MMU is used in Shuttle missions to increase the crewmember's mobility in zero-g. A new EVA mobility system containing its own electrical power, propulsion system, and controls should be developed for the planetary/Lunar surfaces. The range of a system such as this may be on the order of 30 kilometers (approximately 20 miles). Excursions such as this will require navigation and communication aids.

Presently Shuttle EVA missions use a pre-flight prepared cuff-checklist containing procedures and reference data for performing EVA tasks. It also contains procedures which aid in the diagnosis and resolution of an EMU failure. Although this system is functional, it has proven to be physically cumbersome and application-limited. A viable alternative such as a graphics/text interactive display system would be a vast improvement.

Current EVA tool designs have ranged from common tools modified for EVA tasks to specialized tools designed for mission-specific tasks. Approximately one third of the total number of Space Shuttle tools are specific tools for certain contingencies. Future EVA tool development should emphasize effective multi-purpose features and general applications. Because of the exploratory nature of the planetary missions, new tools must be developed for surface applications.

The following section is an overview of the project approach. The project is broken up into three phases with the final phase representing a prototype or breadboard deliverable. The first phase of each of the four-digit boxes in the WBS will be requirements definition. This will include an assessment of the EVA equipment requirements based on mission, environment, and task definitions. State-of-the-art technology will then be applied to the requirements to develop concepts. The deliverable from this first phase is a requirements definition report. In the second phase, the concepts will be modeled and tested experimentally in order to measure the effectiveness of the proposed system or hardware in meeting the requirements. A quantitative report will be the deliverable of the second phase showing the trade-off (gains and losses) associated with the new concept. The third and final phase will be the fabrication, development, and testing of a proof-of-concept hardware or system demonstrator.

The demonstrator will be evaluated in a simulated EVA mission environment. A technology readiness report will document the results of the evaluation. Upon delivery of the satisfactory final phase report the project will transfer to an operational center for support.

2.6.3.3 Description

Requirements must be identified for EVA ancillary equipment. Mission, environment, and task definitions as defined in the design reference mission will provide a starting point. Requirements can then be established for EVA tools, mobility aids, communication, monitoring, display, and control devices, as well as EVA work system interfaces. The requirements will be applied to existing Shuttle and Space Station hardware and instrumentation. A technological assessment will then be made as to the need for advanced concepts and component/system design.

The purpose of EVA/suit control/displays functions is to provide information for productivity enhancement, safety, and increased performance capabilities. Information needs of suited astronauts for all EVA tasks and functions will be evaluated. The product of this evaluation will be a performance base and technology applications guidelines for EVA control/display of information. Interfaces will be developed between various internal and external systems including remote access to large, interactive visual databases. Concepts for navigation aids and critical-situation contingency support equipment such as flares, homing devices, and transponders (astronaut identification and tracking system) will be explored. A trade-study will be done to evaluate the utility of head-up display vs. clipboard-type display for EVA work-task information. Concepts will be assessed through in-house trade studies and experiments and through contracts to develop proof-of-concept hardware/software models for in-house man/system testing. Breadboard development of the most promising design will be accomplished. Testing will follow in a simulated EVA mission environment.

Means of assisting personal mobility will be examined as a possible alternative to walking, running, or bounding. Simple aids will be considered for the purpose of facilitating horizontal rather than vertical movement (the overriding tendency in a low gravity, low surface-friction environment). Self-propelled and motorized modes of transportation will also be explored. EVA work aids may include pull-along equipment and tool transporters. Also, portable safe-havens or way-stations may be needed to extend stay-duration at remote sites. Technology demonstrator mobility and work aids will be developed for testing in an appropriate simulated planetary/Lunar environment.

EVA tool development will emphasize effective multi-purpose features and general applications. Hand-driven and power tools will be explored for use with pressure suit gloves or end-effectors and the interface requirements will be defined for workstation designers. The need for auxiliary equipment such as body/foot restraints, tool aprons, and sample carriers will be evaluated. Test units will be built and tested using partial-g simulations such as KC-135 parabolic flights.

Efficient equipment interfaces with the suited astronaut and the environment are needed for productive, safe EVA. Some high-priority specifications that need to be defined are:

- glove dexterity and suited-reach envelopes as they affect the prime working area where controls may be installed

- human factors measurements of the trade-off between voice inputs and hard-wired command systems

- supervisory communications and control of robotic assistants and autonomous construction equipment

- EVA helmet visor electrostatic surface charge and implications for impairment of vision due to the attraction of Martian dust

2.6.3.4 Schedule

See Figure 2.6.3-1.

Figure 2.6.3-1 Schedule

WBS 1.3.3 EVA ANCILLARY EQUIPMENT

Project Element	*89*	*90*	*91*	*92*	*93*	
			Fiscal Year			
• 1.3.3.1 Mobility Aids						
- Requirements definition		//////////				
- Trade studies		//////////	//////////			
- Concept evaluation				//////////	//////////	//(FY94)
• 1.3.3.2 EVA Tools						
- Requirements definition			//////	//////		
- Concept evaluation				/////	//////////	//(FY95)
• 1.3.3.3 Displays and Controls						
- Requirements definition		//////////				
- Trade studies		//////////	//////////	//////////		
- Concept evaluation					//////////	//(FY97)
• 1.3.3.4 EVA Work System Interfaces						
- Requirements definition		//////////	//////////			

2.6.3.5 Milestones and Deliverables

See Figure 2.6.3-2.

Figure 2.6.3-2 Major Milestones and Deliverables

WBS 1.3.3 EVA ANCILLARY EQUIPMENT

Project Element	*Fiscal Year* 89	90	91	92	93
• 1.3.3.1 Mobility Aids					
- Mobility concepts definition				Δ	
• 1.3.3.2 EVA Tools					
- Generic tool kit					Δ
• 1.3.3.3 Displays and Controls					
- EVA work/task displays and controls concept selection				Δ	
• 1.3.3.4 EVA Work System Interfaces					
- Interface requirements definition					Δ

2.6.3.6 Resource Allocations

The resource allocation is shown in Table 2.6.3-1.

Table 2.6.3-1 Resource Allocation

WBS 1.3.3 EVA ANCILLARY EQUIPMENT

	Fiscal Year ($K) 89	90	91	92	93
WBS 1.3.3.1 Mobility Aids					
ARC	0	100	100	80	150
JSC	0	100	100	90	150
LaRC	0	0	0	0	0
WBS 1.3.3.2 EVA Tools					
ARC	0	0	15	15	30
JSC	0	0	15	15	25
LaRC	0	0	0	0	0
WBS 1.3.3.3 Displays and Controls					
ARC	0	50	75	100	150
JSC	0	75	75	50	0
LaRC	0	25	75	100	150
WBS 1.3.3.4 EVA Work System Interfaces					
ARC	0	0	0	0	0
JSC	0	0	25	50	125
LaRC	0	0	0	0	0
Total ARC	0	150	205	210	330
Total JSC	0	175	200	190	300
Total LaRC	0	25	75	100	150
Total for Project Sub-Element	0	350	480	500	780

2.6.4 System Integration and Test

2.6.4.1 Objectives

The objective of thSystem Integration and Test (WBS 1.3.4) sub-element is to integrate and test the components of EVA suits and equipment as an integrated system. In addition, suit and equipment logistics models will be further defined to insure that models of logistics supportability are established and verified. Test methodology and requirements obtained from WBS 1.1 will be further refined into a NASA Suits and Equipment Standard. This standard will be incorporated into the integrated EVA system requirements for the basis of system testing in WBS 1.4.2. The WBS 1.3.4 sub-element consists of the following task areas:

- System Integration (WBS 1.3.4.1)
- System Test (WBS 1.3.4.2)
- Logistics and Support (WBS 1.3.4.3)

As test methods and system requirements are defined and demonstrated, they will be incorporated into separate appendices by mission scenario into NASA Standard 3000 Man-Systems Integration Standards. This will insure that requirements are distributed to all parties in a timely fashion. Modifications to the requirements as a result of testing under this WBS must be addressed by management. A management test requirements control system will be established to insure that justification for relaxing or increasing system performance requirements is documented and justified.

2.6.4.2 Technical Approach

The requirements for this sub-element will begin to be defined in FY89 under the systems study efforts of WBS 1.1. Mission requirements will be defined in WBS 1.1.1. Human requirements will be developed in WBS 1.1.2, while EVA system integration requirements will be developed in WBS 1.1.3. Prototype EVA pressure suits will be developed in WBS 1.3.1, with technology demonstration testing occurring in WBS 1.3.1.4, prototype gloves and end-effectors in WBS 1.3.2, and EVA ancillary equipment will be established in WBS 1.3.3. Actual testing of prototype hardware to verify that the hardware meets established test requirements is scheduled to begin in FY91 and continue at an increasing level of activity through FY95.

2.6.4.3 Description

System Integration (WBS 1.3.4.1): This task area will insure that all prototype suits, gloves, and ancillary equipment will mate properly and conform to the interface requirements developed under WBS 1.1.3.2. Testing will include fit-check demonstrations. Procedural guidelines will be identified to establish checklist control of critical interface connections. Checklists will be incorporated into system operation technical orders for use and verification in integrated system testing (WBS 1.4.2).

System Test (WBS 1.3.4.2): Integrated EVA suits and equipment will be evaluated according to the methodology and requirements established in system studies (WBS 1.1). A NASA Standard Suit and Equipment Test Plan will be established to assess not only hardware performance but also reliability, maintainability, manufacturability, and life cycle cost to establish a systems approach to the design decision process. Suits and equipment will be evaluated in simulated zero- and variable-g environments using underwater neutral buoyancy, KC-135, and suspension methods. Range-of-motion performance will be assessed using the state-of-the-art system selected in WBS 1.1.3. Suit and glove joint torque measurements will be assessed using current test methods. Life cycle testing will be performed to evaluate expected system use. Radiation and thermal tests using vacuum chambers and other test methods will be used to verify models developed in WBS 1.1.1.

Logistics and Support (WBS 1.3.4.3): Methods to evaluate and verify logistics supportability developed in WBS 1.1.3.1 and WBS 1.1.3.4 will be used to assess integrated EVA suits and equipment. Emphasis will be on the establishment of cleaning and servicing guidelines as well as defining supportability and spare parts requirements.

2.6.4.4 Schedule

See Figure 2.6.4-1.

Figure 2.6.4-1 Schedule

WBS 1.3.4 SYSTEM INTEGRATION AND TEST

Project Element	*Fiscal Year* 89	90	91	92	93	
• 1.3.4.1 System Integration				//////////	//////	
• 1.3.4.2 System Test			/////	//////////	//////////	//(FY96)
• 1.3.4.3 Logistics and Support					//////////	/(FY95)

2.6.4.5 Milestones and Deliverables

Milestones and deliverables for this WBS element will be provided in subsequent updates to this plan.

2.6.4.6 Resource Allocation

The System Integration (WBS 1.3.4.1) task area will be funded under WBS 1.1.3.2 for initial study requirements in FY90 and FY91. FY90 funding for this effort will be provided in a future update to this plan.

Testing effort for the System Test (WBS 1.3.4.2) task area is scheduled to begin in FY91 with a projected requirement of $120K. Testing activity will increase in FY92 and FY93.

Logistics and Support (WBS 1.3.4.3) studies will be funded under WBS 1.1.3.1 and WBS 1.1.3.3 through FY93. Additional effort for this task area will be provided in a future update to this plan.

See Table 2.6.4-1 for the resource allocation.

Table 2.6.4-1 Resource Allocation

WBS 1.3.4 SYSTEM INTEGRATION AND TEST

	Fiscal Year				
	89	*90*	*91*	*92*	*93*
• WBS 1.3.4.1 System Integration	0	0	0	0	TBD
• WBS 1.3.4.2 System Test	0	0	120	250	220
• WBS 1.3.4.3 Logistics and Support	0	0	0	0	TBD

2.7 INTEGRATED EVA SYSTEM

2.7.1 Hardware/Software Integration

2.7.1.1 Objectives

The objective of the Hardware/Software Integration (WBS 1.4.1) sub-element is to coordinate the efforts in WBS 1.1 through WBS 1.3 to provide an integrated systems approach toward development of an EVA system (suit, PLSS, and ancillary equipment). Specific responsibilities include:

- pverification and validation of any software elements as they interface and affect hardware function and performance

- failure modes and effects analyses for mission-specific integrated EVA systems

2.7.1.2 Technical Approach

Future long-duration space missions will require a degree of autonomy from ground-based support and logistics systems much greater than that for space missions of the past. These missions will require EVA systems which are extremely reliable, supportable, and user friendly. Accordingly, special emphasis must be placed on safety, economics, automation, and interfaces with automated systems. Analysis is a vital tool in providing the insight, understanding, and confidence necessary in evaluating systems technologies.

The scope of this sub-element comprises systems and operational requirements, systems interfaces, systems autonomy and automation, reliability and quality assurance, and failure modes and effects analysis.

Attention will be given to satisfying operational, performance, and reliability requirements. Interfaces for intercommunication between subsystems, test procedures, and testbed requirements will be defined. Performance of test procedures will be within WBS 1.4.2.

2.7.1.3 Description

This sub-element is a high-level integration function and is dependent on suit, glove and end-effector, PLSS, and ancillary equipment technology development. The hardware concepts definition is to occur in the first half of the 10-year Pathfinder program. Once mission-specific technologies have been selected for the suit (PLSS, gloves, tools, etc.), the integration tasks will begin. Software operation will be validated with its interfacing hardware; failure modes of the integrated system will be assessed. All of these analyses are necessary and important, but no work is appropriate until prototype development is begun in FY93.

2.7.1.4 Schedule

The schedule for this element is illustrated in Figure 2.7.1-1.

Figure 2.7.1-1 Schedule

WBS 1.4.1 HARDWARE/SOFTWARE INTEGRATION

Project Element	Fiscal Year 89	90	91	92	93	
• Verification procedures						Δ FY94-95
• Hardware/software operational verification						Δ FY95-96
• Failure modes and effects analyses						Δ FY97

2.7.1.5 Milestones and Deliverables

The major deliverables are listed in Figure 2.7.1-2.

Figure 2.7.1-2 Major Milestones and Deliverables

WBS 1.4.1 HARDWARE/SOFTWARE INTEGRATION

Project Element	Fiscal Year 89	90	91	92	93	
• Hardware/software verification procedures document						Δ (FY95)
• Failure modes and effects report						Δ (FY97)

2.7.1.6 Resource Allocation

No funding is allotted to this sub-element in FY89. Zero funding continues through FY92. It is to be noted that integration functions at the PLSS system level and the suit system level may begin before this, but at the level of an integrated EVA work system (PLSS, suit, glove/end effector, tools, mobility aids, etc.), integration efforts begin in FY94 at a low level and continue thereafter at an intermediate level of effort.

2.7.2 Systems Test

2.7.2.1 Objectives

The objective of the Systems Test (WBS 1.4.2) sub-element is to demonstrate that selected PLSS and EVA suit and equipment chosen for a designated mission scenario will safely meet all mission requirements. Integrated testing methods incorporating simulated environments developed in WBS 1.1 will be used to demonstrate system performance. Logistical analysis requirements will be verified to demonstrate system supportability. System reliability, manufacturability, maintainability, and life-cycle cost projections will be assessed to provide management with information necessary to evaluate competing systems for a reference mission.

As test methods and system requirements are demonstrated, they will be incorporated into NASA Standard 3000 Man-Systems Integration Standards. This will insure that requirements are distributed to all parties in a timely fashion. Modifications to the requirements as a result of testing under this WBS will be controlled by the ARC Project Manager. A test requirements control system will be established to insure that justification for changing requirements is documented and approved.

2.7.2.2 Technical Approach

This work effort represents the culmination of all efforts for PLSS and EVA suit and equipment. As such, efforts are not projected to begin until FY95.

2.7.2.3 Description

As prototype system hardware is developed, demonstrated, and evaluated, decisions will be made to select the most promising designs. As the PLSS, suits, and equipment are demonstrated and tested, test plans will be developed to test the entire integrated system. At this point it is too early to state with certainty which methods will be used. However, an integrated system may be demonstrated in a partial-g suspension system to evaluate integrated system parameters.

2.7.2.4 Schedule

Integrated system testing is scheduled to begin in FY95. A more detailed schedule will be provided in future updates to this plan.

2.7.2.5 Milestones and Deliverables

Specific milestones and deliverables will be provided in future updates to this plan.

2.7.2.6 Resource Allocation

No effort is required until FY95. Resource requirements will be provided in future updates to this plan.

2.7.3 Systems Logistics and Support

2.7.3.1 Objectives

The objectives of the Systems Logistics and Support (WBS 1.4.3) sub-element are to:

- develop and demonstrate the logistics management and support technologies needed for future EVA operations

- apply these technologies to the support of the technology demonstrator EVA suit system during the test and demonstration phase

2.7.3.2 Technical Approach

Systems Logistics and Support in the context of this project includes systems monitoring, diagnostics, maintenance, repair, inventory, supply, and logistics information. Logistics management includes determining the status of the logistic system (inventory, maintenance, supply) and appropriate systems and elements. It also includes logistics information processing and display, determination of corrective action (manual or automatic), policy determination, and operations related to carrying out logistics functions. Earth-based elements of the logistics system are included to the extent that they affect or interface with the on-board logistics system.

Future long-duration space missions will be supported by highly-automated diagnostic and test equipments. Since spare parts will be delivered infrequently and crewmembers will have relatively little time to maintain and repair on-board systems, they must be able to diagnose, maintain, and repair their equipment with a minimal amount of specialized training and skill. Their primary mission will, and should, occupy most of their attention. This implies the need for systems concepts which are supportable, i.e. testable, diagnosable, maintainable, and supplied with the necessary replacement parts when needed. It also implies the need for diagnostic and test equipments, tools, procedures, displays and information systems to help the crew perform logistics management and systems support functions safely, economically, and effectively.

The task of determining how to provide interfaces between the crew and an integrated logistics system is far from trivial. Particular attention must be paid to:

- the presentation of information which the crew needs to carry out monitoring, diagnostics, maintenance, inventory and supply management functions

- the presentation of information to the crew while they are performing maintenance tasks

- the interaction of the crew with the logistics information system to establish and carry out logistics and support operations policies responsive to new situations

- alerting the crew of potentially dangerous situations

It has been common in the past to begin the design of ground support systems (GSE) after a system design or concept has been frozen, then to select or adapt some available set of support equipment, and to not pay particular attention during the design phase to the supportability of a system. The net result of this approach has been extremely high support costs and the unavailability of systems when they are needed. The alternative to this is to design a system with integrated test capabilities: test point locations, test inputs, and expected outputs must be defined; diagnostic and maintenance procedures must be established; crew interfaces for interactive diagnostic procedures must be developed; documentation and databases must be readily accessible.

Techniques for analyzing the supportability, reliability, availability, maintainability, and life-cycle cost of weapon systems have been developed and standardized by the Department of Defense. Some of these techniques have been studied and advocated for possible application to the Space Station program. Techniques such as these can be of particular value in developing advanced EVA suit systems designs, logistics management concepts, support systems, and procedures, and in evaluating alternative concepts. It is the intent of this sub-elementto adapt these techniques, where possible, to the needs of the EVA/Suit Project, and to develop new techniques where needed. WBS Task 1.1.3.3 will provide an assessment of available techniques, develop them further as needed, and provide the analytical and simulation capability needed for this effort.

Outputs of this effort will be timed to be responsive to the needs of other tasks of the EVA/Suit Project, including support of the technology demonstrator suit system. However, start of this effort is dependent on the results obtained from WBS 1.1.3.3. It is therefore imperative that WBS 1.1.3.3 begin as soon as possible.

The five main technology task areas for this effort are:

- Diagnostics (WBS 1.4.3.1)
- Maintenance and Repair (WBS 1.4.3.2)
- Inventory Management and Supply (WBS 1.4.3.3)
- Information Management (WBS 1.4.3.4)
- Training (WBS 1.4.3.5)

Logistics management and support studies (WBS 1.1.3.3) will provide input information needed to address these five task areas, e.g. math models, simulations, crew-systems interface concepts, design guidelines, database requirements, integrated logistics management and supportability concepts, and systems synthesis methodologies. These inputs are needed for development of hardware and software systems needed to demonstrate technology readiness of logistics management and support systems for future space missions.

WBS 1.1.3.3 will help define requirements and one or more logistics management and support systems concepts for future space missions. The concept(s) selected will be used as a basis for designing a technology demonstration system. The technology demonstrator will have two purposes:

- demonstrate the logistics and support technologies need for future EVA operations

- support the technology demonstrator EVA suit system during the test and demonstration phase

Diagnostics (WBS 1.4.3.1): The diagnostics approach envisioned for future space missions is based on application of artificial intelligence/expert systems technology. It comprises a database of information describing the characteristics of the system and its components, sensors to detect relevant system parameters, information processing, displays, controls, and the human operator. Systems status, performance characteristics, detection of failures, fault isolation, failure prediction, and description of procedures will be accomplished through an interactive process between the expert system and the human operator. The design of the interfaces between the human operator and the diagnostic system will be established through manned simulations.

Maintenance and Repair (WBS 1.4.3.2): Maintenance and repair procedures will be defined as a step in the diagnostic process above and presented to the human operator via the interactive display system. The configuration of the maintenance and repair workstation will be accomplished by this task area with inputs from WBS 1.1.3.3.

This task area will also define requirements for standard tools, special tools, and support equipment and, where necessary, develop them.

Inventory Management and Supply (WBS 1.4.3.3): Resupply for long-duration missions will be very infrequent, perhaps months or years apart. At the same time there will be limits on the amount of inventory which can be maintained on board the space ship or on the Lunar or planetary bases. It is necessary, therefore, to have an inventory management system which can anticipate needs for spare parts and consumables relevant to EVA operations, arrange for them to be delivered when needed, and maintain inventories at adequate, but not excessive, levels. To accomplish this, inventory management simulations will be developed and used to define an inventory management approach based on component characteristics such as reliability, mean-time-to-failure, etc.

Information Management (WBS 1.4.3.4): The function of the logistics management and support information management system is to process the sensor data, incorporate database information and operator inputs, and to interact with the human operator to generate the diagnostic, maintenance, repair, inventory and supply data and information. The technology demonstrator will probably use a personal computer to serve this function. An operational system in space may use a workstation terminal interfaced with the information management system on board the space vehicle or installed at a Lunar or Martian base. Requirements for the design of an operational system for Pathfinder missions and for a technology demonstration system will be based on results of simulations and mission studies.

Training (WBS 1.4.3.5): Logistics management and support training is not often considered as part of a research and technology program. However, it should be included because of the advanced nature of the logistics management and support concepts which will be developed in this project, e.g. application of expert systems technology to diagnostic systems status and performance, and the interaction of the crew with this system. The manned simulations will be used to gain insights on how to train future astronauts in the use of advanced logistics management and support systems, including diagnostics, maintenance, repair, information processing, and interaction with the information management system.

2.7.3.3 Description

The narrative for this section will be provided in updates to this plan.

2.7.3.4 Schedule

See Figure 2.7.3-1.

Figure 2.7.3-1 Schedule

WBS 1.4.3 SYSTEMS LOGISTICS AND SUPPORT

Project Element	89	90	91	92	93	
• 1.4.3.1 Diagnostics			/////	//////////	//////////	/(FY95)
• 1.4.3.2 Maintenance and Repair				/////	//////////	/(FY95)
• 1.4.3.3 Inventory Management & Supply				/////	//////////	/(FY96)
• 1.4.3.4 Information Management					//////////	/(FY96)

Fiscal Year

2.7.3.5 Milestones and Deliverables

Specific milestones and deliverables will be provided in future updates to this plan.

2.7.3.6 Resource Allocation

A tabulation of resources will be provided in future updates to this plan. No funding is allotted in FY89.

2.8 FIVE YEAR PLANNING SUMMARY

2.8.1 Fiscal Year 1989 Schedule

Figure 2.8.1-1 is a list of task areas to be initiated in FY89. Also included is the performing center and funding level. The task areas are arranged according to the Work Breakdown Structure.

Figure 2.8.1-1 Fiscal Year 1989 Schedule

WBS # and Element	*Performing Center*	*FY89 Funding*
1.1.2 Human Requirements Definition		
1.1.2.1 Human Factors	ARC JSC	50 50
1.1.2.2 Physiological/Medical Requirements	ARC JSC	150 150
1.1.3 EVA Work Systems Integration		
1.1.3.1 Modeling and Trade Studies	JSC	60
1.2.1.Thermal Control Systems		
1.2.1.1 Subsystem Analytical Modeling	ARC	35
1.2.1.2 Heat Storage	ARC	75
1.2.1.5 Heat Rejection	ARC JSC	75 100
1.2.2. Atmospher Control		
1.2.2.1 Subsystem Analytical Modeling	ARC JSC	25 100
1.2.3. Monitoring and Control		
1.2.3.2 Automated Control Technology	ARC	50
1.3.1. Pressure Suit Technology		
1.3.1.1 Suit Materials and Structures	ARC JSC	100 100

2.8.2 Five-Year Schedule

A five-year schedule for the EVA/Suit Project, at the 4-digit WBS level, is illustrated in Figure 2.8.2-1. A greater level of schedule detail can be found in the individual sub-element schedules in Sections 2.4.1 through 2.7.3.

The program flow is evident in the starting dates of the project elements. Requirements definition and specific technology concepts are investigated in the immediate years, producing breadboard or proof-of-concept demonstrations of the technologies. From these demonstrations and from trade studies and analyses, mission-specific technology choices will be made; these technologies will be further refined. Hardware integration efforts begin approximately four years into the program, with the fabrication of a suit technology demonstrator(s) and an integrated PLSS(s).

Beyond the initial five years of technology development is a series of integrations and tests, at higher levels. This is explained in more detail in Section 2.9.

Figure 2.8.2-1 Five-Year Schedule

Project Element	*Fiscal Year* 89	90	91	92	93
1.1 SYSTEMS STUDIES					
• 1.1.1 Mission Requirement Definition					
1.1.1.1 Environmental Considerations		//////////	//////////		
1.1.1.2 EVA Task Definition		//////////	//////////	//////////	
1.1.1.3 Design Reference Mission		/////	//////////	//////////	///////
• 1.1.2 Human Requirements Definition					
1.1.2.1 Human Factors	/////	//////////	/////		
1.1.2.2 Physiological/Medical Rqmts	//////////	//////////	//////////		
• 1.1.3 EVA Work Systems Integration					
1.1.3.1 Modeling and Trade Studies	/////	//////////	//////////	//////////	//////////
1.1.3.2 Interface Definition and Rqmts		//////////	//////////	//////////	
1.1.3.3 Logistics and Support		//////////	//////////	//////////	//////////
1.1.3.4 Test Rqmts Definition				//////////	//////////(FY94)

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Figure 2.8.2-1 Five-Year Schedule (continued)

Project Element	*Fiscal Year* 89	90	91	92	93	
1.2 PORTABLE LIFE SUPPORT SYSTEMS						
• 1.2.1 Thermal Control Systems						
1.2.1.1 Subsystem Analytical Modeling	//////////	//////////	//////////	//////////	//////////	(FY98)
1.2.1.2 Heat Storage	/////	//////////	//////////	//////////	////	
1.2.1.3 Heat Acquisition			/////	/////		
1.2.1.4 Heat Transport		//////////	//////////	//////////		
1.2.1.5 Heat Rejection	/////	//////////	//////////	//////////	////	
1.2.1.6 Subsystem Test				/////	//////////	(FY94)
• 1.2.2 Atmosphere Control						
1.2.2.1 Subsystem Analytical Modeling	//////////	//////////	//////////	//////////	//////////	(FY97)
1.2.2.2 O_2 Supply		//////////	//////////	//////////	//////////	
1.2.2.3 CO_2 Control		//////////	//////////	//////////	//////////	
1.2.2.4 Trace Contaminant & Microbial Control		//////////	//////////	//////////		
1.2.2.5 Humidity Control		//////////	//////////	//////////	//////////	
1.2.2.6 Subsystem Test				//////////	//////////	
• 1.2.3 Monitoring and Control						
1.2.3.1 Subsystem Analytical Modeling		//////////	//////////	//////////		
1.2.3.2 Automated Control Technology	//////////	//////////	//////////	//////////	//////////	
1.2.3.3 Display Technology		//////////	//////////	//////////	//////////	
1.2.3.4 Subsystem Test		//////////	//////////	//////////	//////////	
• 1.2.4 System Integration						
1.2.4.1 Requirements		//////////	//////////	//////		
1.2.4.2 Analysis		//////////	//////////	//////////	/////	
1.2.4.3 Support Equipment & Interfaces					/////	(FY98)

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Figure 2.8.2-1 Five-Year Schedule (continued)

Project Element	*89*	*90*	*91*	*92*	*93*	
1.3 EVA SUITS AND EQUIPMENT						
• 1.3.1 Pressure Suit Technology						
1.3.1.1 Suit Materials and Structures	//////	//////////	//////////	//////		
1.3.1.2 Suit Components & Mobility Elements		//////////	//////////	//////		
1.3.1.3 Suit Configurations			//////////	//////////	//////	
1.3.1.4 Suit Technology Demonstrator				//////////	//////////	/(FY95)
• 1.3.2 Gloves and End-Effectors						
1.3.2.1 Gloves		//////////	//////////	//////////		
1.3.2.2 End-Effectors		//////////	//////////	//////////	//////	
• 1.3.3 EVA Ancillary Equipment						
1.3.3.1 Mobility Aids		//////////	//////////	//////////	//////////	//(FY94)
1.3.3.2 EVA Tools			//	//////////	//////////	//(FY95)
1.3.3.3 Displays and Controls		//////////	//////////	//////////	//////////	//(FY97)
1.3.3.4 EVA Work System Interfaces		//////////	//////////			
• 1.3.4 System Integration and Test						
1.3.4.1 System Integration				//////////	//////////	/(FY95)
1.3.4.2 System Test			/////	//////////	//////////	//(FY96)
1.3.4.3 Logistics and Support					//////////	/(FY95)

Fiscal Year

continued on next page

Figure 2.8.2-1 Five-Year Schedule (continued)

Project Element	*89*	*90*	*91*	*92*	*93*	
1.4 INTEGRATED EVA SYSTEMS						
• 1.4.1 Hardware/Software Integration						(FY94-95)
• 1.4.2 Systems Test						(FY95-98)
• 1.4.3 Systems Logistics & Support			/////	//////////	//////////	(FY96)

Fiscal Year is printed as a heading above the 89–93 columns.

2.8.3 Milestones, Accomplishments, and Deliverables

The major milestones, accomplishments, and deliverables of the EVA/Suit Project are listed in Figure 2.8.3-1. Requirements definition in the years 1989-1993 will provide guidelines to hardware and software designers and will aid in the evaluation and selection of technology options. The products of requirements investigations will be reports. Technology concepts investigations will culminate in system demonstration, hardware fabrication, evaluation, and subsequent design refinements.

An integrated PLSS(s) will be fabricated and tested in FY95, concurrently with the production of a Suit Technology Demonstrator, to be completed in 1995. These items will be integrated with ancillary equipment and the entire EVA system will be evaluated. The completion of integrated systems tests is anticipated in FY98.

Figure 2.8.3-1 Milestones, Accomplishments, and Deliverables

Project Element	*Fiscal Year* 89	90	91	92	93
1.1 SYSTEMS STUDIES					
• Environmental requirements				Δ	
• EVA task descriptions				Δ	
• Design reference missions					Δ
• Human biomech. capabilities quantified			Δ		
• CO_2 partial pressure requirements		Δ			
• Radiation protection requirements			Δ		
• Medical monitoring requirements				Δ	
• Logistics model guidelines			Δ		
• Integrated logistics system concepts					Δ
• Test requirements					Δ

continued on next page

Figure 2.8.3-1 Milestones, Accomplishments, and Deliverables (continued)

Project Element	Fiscal Year 89	90	91	92	93	
1.2 PORTABLE LIFE SUPPORT SYSTEM						
• Analysis of current concepts		Δ				
• Heat acquisition concepts				Δ		
• Heat transport concepts			Δ			
• Advanced refrig. proof-of-concept				Δ		
• Atmosphere control. subsystem breadboard						
- Zero-g				Δ		
- Lunar					Δ	
- Mars					Δ	
• Automatic control breadboard						
- Zero-g			Δ			
- Lunar				Δ		
- Mars					Δ	
• Display breadboard					Δ	
• Integrated PLSS						
- Zero-g						Δ(FY94)
- Lunar						Δ(FY95)
- Mars						Δ(FY95)

continued on next page

Figure 2.8.3-1 Milestones, Accomplishments, and Deliverables (continued)

Project Element	*89*	*90*	*Fiscal Year* *91*	*92*	*93*	
1.3 EVA SUITS AND EQUIPMENT						
• Rotary sealed bearing demonstrator				Δ		
• TMG materials/structure demonstrator				Δ		
• Boot fabrication					Δ	
• EVVA/helmet fabrication					Δ	
• Configuration selections					Δ	
• Suit technology demonstrator						Δ(FY95)
• Prototype blow-molded glove					Δ	
• End-effector demonstrator fabrication				Δ		
• Work/task displays and controls concept selection					Δ	
• Mobility concepts definition					Δ	
• Generic tool kit					Δ	
• Interface rqmts definition					Δ	
1.4 INTEGRATED EVA SYSTEMS						
• Operational verification procedures						Δ(FY95)
• Failure modes and effects analysis						Δ(FY97)
• Integrated EVA system test complete						Δ(FY98)

2.9 LONG RANGE PLAN

The flow for the EVA/Suit element of Pathfinder is illustrated in Figure 2.9-1. Efforts during the first phase of the program will concentrate on definition of mission, medical and physiological requirements. The importance of this phase is emphasized and the support of HQ Codes E and Z is vital to the success of the program. The culmination of the mission requirements definition will be the establishment of design reference missions in 1991. This is the detailed timeline associated with a proposed mission. It will serve as the basis for the evaluation of system concepts and eventually for the determination of test requirements for EVA hardware. The results of all requirements definition efforts will be design guidelines that will help to focus design efforts in all elements of the program. The design guidelines will be periodically updated as the project progresses.

Design efforts in nearly all areas will begin concurrently with requirements definition for identification of a maximum of possible technologies. The design of a translation- and work-aids and tools will lag the more extensive efforts in pressure suits, gloves, end-effectors, and portable life support systems to allow time for EVA task definition.

In the element of pressure suits, current and past suit concepts will serve as the foundation of advanced planetary/Lunar exploration suits. Resources will be channeled into enhancing the manufacturability, reliability, maintainability, and weight reduction of the suit components. Trade studies of various configurations will outline the most suitable configuration(s) for specific missions. The deliverable of this element in the mid 1990's will be a suit technology demonstrator(s).

Similarly, trade studies of various PLSS subsystems will identify the optimal technology choices for specific missions, with respect to mission and physiological requirements. The selected subsystems will be combined into a functional, integrated PLSS prototype in fiscal years 1993 and 1994.

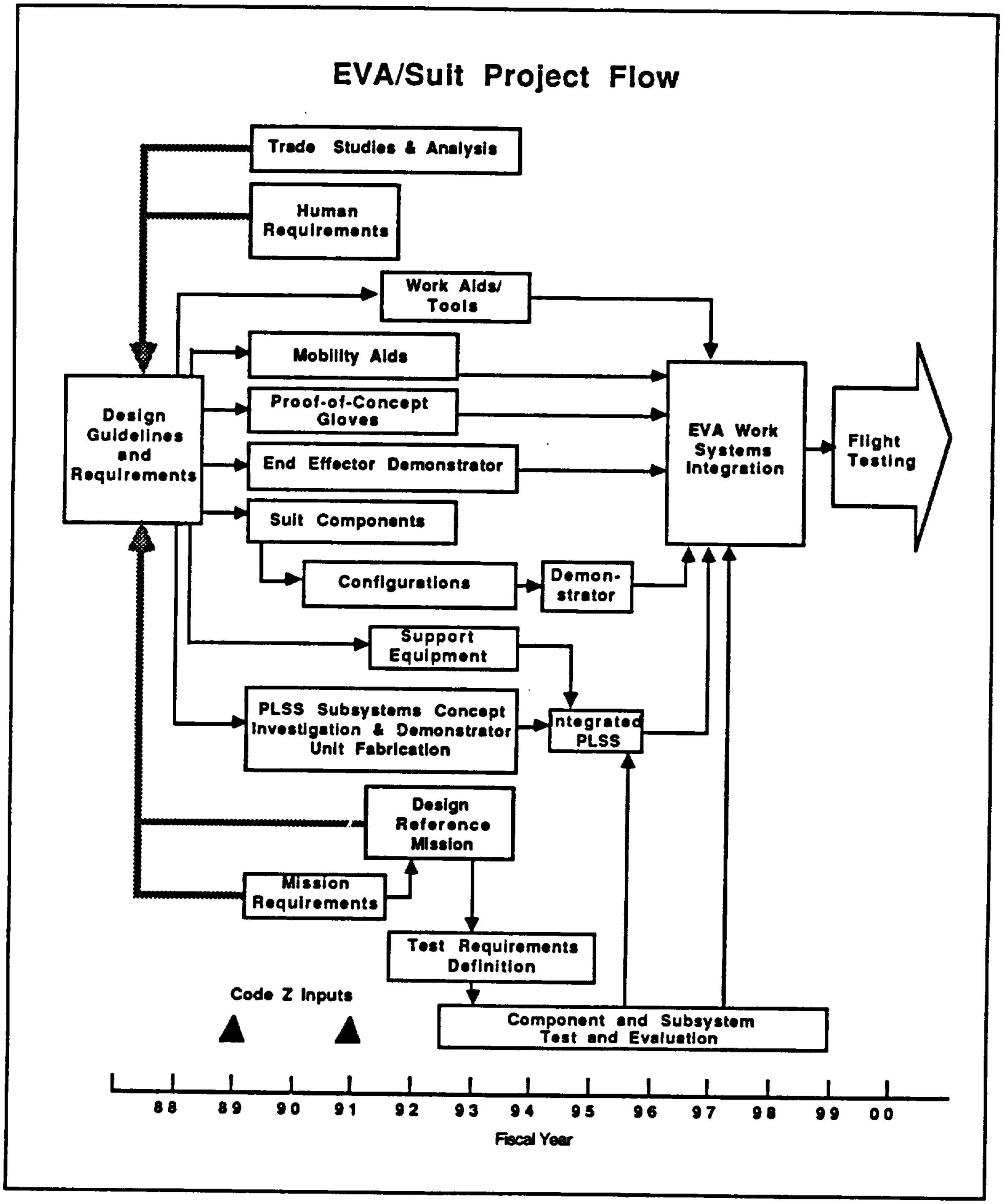
EVA/Suit Project Flow
Trade Studies & Analysis
Human Requirements
Work Aids/ Tools
Mobility Aids
Design Guidelines and Requirements
Proof-of-Concept Gloves
End Effector Demonstrator
Suit Components
Configurations
Demon-strator
EVA Work Systems Integration
Flight Testing
Support Equipment
PLSS Subsystems Concept Investigation & Demonstrator Unit Fabrication
Integrated PLSS
Design Reference Mission
Mission Requirements
Test Requirements Definition
Code Z Inputs
Component and Subsystem Test and Evaluation
88 89 90 91 92 93 94 95 96 97 98 99 00
Fiscal Year

Figure 2.9-1

As in the suit element, ongoing glove programs will be the foundation for future work. A new emphasis will be placed on manufacturability and meeting environmental requirements of the new missions.

Current concepts for advanced end-effector technology have not been fabricated. An initial step in the Pathfinder EVA/Suit Project is the completion of this hardware so the functionality of end-effectors may be evaluated verses the gloved hand for mission-specific tasks. Astronauts will provide valuable input during the evaluation to plan and develop enhancements such as force amplification, compliance, and tactile feedback.

During the second five years of the ten-year Pathfinder Project, the suit technology demonstrator(s) will be combined with other elements of the EVA work system — initially the PLSS and glove prototypes. Various components of the system, and the EVA work system as a whole, will undergo extensive ground-based testing in FY96 through FY98. The final task in the project is flight testing in FY99 and beyond. After completion of successful flight testing, a hardware production phase may be initiated to meet the proposed launch schedule.

3.0 CONTRACTING PLANS

The goal of the Pathfinder Project EVA/Suit Plan as related to contracting plans is to provide the necessary technology and infrastructure for long-duration transit and planetary/Lunar exploration missions. Close collaboration with U.S. universities and industry will support development of the EVA/Suit Project infrastructure and ensure present and future U.S. competitiveness in space technology innovation and development.

3.1 OVERVIEW

Close collaboration between NASA, industry, and academia is required in order to accomplish the goals of the EVA/Suit Project Plan. An assessment of the critical skills required to support the proposed technological development has been conducted and a human resource distribution of in-house and outside personnel has been established as shown in Table 3.1-1.

Table 3.1-1 ARC Personnel Requirements

	Cumulative staff requirement*	*Δ (referenced to FY88)*	*Cumulative contractor requirement*	*Cumulative university requirement*
FY88	3	0	5	1
FY89	8	5	7	2
FY90	11	8	9	2
FY91	15	12	11	3
FY92	15	12	12	3
FY93	15	12	12	3

** Funding requirements are predicated on the assumption that the increase will be civil service complement. To the extent that this does not occur, additional funding will be required for contractor support personnel.*

In conducting the assessment, an evaluation of critical in-house skills required for specific technical areas of emphasis was developed. A further evaluation of the relative supporting contractor and academic roles was conducted. It was determined that an on-site support contract will be required to provide the required range of technical expertise and support. A contract will be negotiated to provide diversified, professional talent in the areas of engineering, computer modeling, and physical/life sciences. Technical skill such as that provided by electrical, electronic, and mechanical technicians will also be required. An attempt will be made to ensure a reasonable balance between in-house and outside activities while ensuring that key in-house technical expertise is given highest priority.

3.2 COLLABORATION MECHANISMS

The Ames Research Center will utilize many traditional and ARC-unique legal mechanisms to collaborate with U.S. universities and industries on EVA/suit activities. Available mechanisms are divided into three categories: Standard Agreements, Small Business Innovation Research Program, and Space Act Agreements.

3.2.1 Standard Agreements

Under the 1978 Federal Grant and Cooperative Agreement Act, Congress standardized the ways NASA and all other federal agencies purchased property and employed persons. The Act provides three mechanisms for federal agency use to carry out procurement activities: contract, grant, and cooperative agreement.

Procurement contract: NASA uses the procurement contract to acquire services and property for its direct use and benefit through purchase, lease, or barter (31 U.S.C. 6303). NASA solicits requests for proposals (RFPs) where the extent of agency guidance is definitive. Unsolicited proposals relevant to agency mission requirements are also accepted for both general and NASA-specified program goals.

Grant agreement: NASA uses the grant agreement to pay or otherwise compensate the recipient to carry out an activity within NASA's charter. Under a grant agreement, NASA does not benefit directly and does not require its substantial involvement to carry out the activity (31 U.S.C. 6304). The grant agreement is NASA's preferred instrument for support or stimulation of basic research of interest to the agency.

Cooperative agreement: The cooperative agreement permits NASA to pay or otherwise compensate the recipient to carry out an activity within NASA's charter and work closely with the recipient (31 U.S.C. 6305). Cooperative agreements are generally used for research projects possible only through extensive joint NASA/recipient activities.

3.2.2 Small Business Innovation Research (SBIR) Program

The Small Business Innovation Development Act of 1982 enables NASA and other federal agencies to conduct SBIR programs to stimulate technology innovation in the private sector, strengthen the role of small businesses in meeting federal research and development needs, increase commercial application of federally supported research results, and foster minority and disadvantaged participation in technology innovation (15 U.S.C. 638).

NASA determines the technical topics and subtopics to be included in its SBIR solicitation and chooses awardees according to established criteria. Phase I and Phase II SBIR programs use the procurement contract to fund awardees. Phase III activity is conducted by small businesses using nonfederal money to pursue commercial applications.

3.2.3 Space Act Agreements

Space Act Agreements derive authority from the National Aeronautics and Space Act of 1958. By definition, Space Act Agreements do not fall within the scope of legislatively defined procurement, grant, or cooperative agreements and are bound only by parameters set by NASA Management Instructions (NMIs).

Memorandum of Understanding (MOU): MOUs are used by NASA to enter into a relationship with another party, expressing an intent by the parties to negotiate and outline details toward a fuller agreement. MOUs are used for establishing relationships between NASA field installations with industries, universities, nonprofits, or other governmental entities. With a profit-making entity, MOUs can be used by NASA for either reimbursable or nonreimbursable arrangements.

Technical Exchange Agreement (TEA): The TEA, a recently developed mechanism sponsored by NASA's Office of Commercial Programs (OCP), facilitates special relationships between NASA and domestic industries. Under a TEA, NASA and a company agree to undertake a ground-based research project that will result in potential application to commercial space. The TEA provides an incentive, at minimal risk, for a non-aerospace firm to become familiar with space technology and apply findings to the firm's product line. Each party funds its own participation and shares the research results.

Joint Endeavor Agreement (JEA): The JEA, another OCP-sponsored mechanism, is an agreement between NASA and a firm to encourage early space ventures and demonstrate the use of space technology to meet marketplace needs. The firm selects an experiment and develops the required flight hardware at its own expense. As incentive, NASA agrees to provide free Shuttle flights for experiments meeting basic criteria and allows the firm to retain certain exclusive rights in patents and proprietary information that may result from activities conducted under the JEA. NASA receives sufficient data to evaluate the significance of the experiment's results.

Ames Joint Enterprise for Aerospace Research and Technology Transfer (Joint Enterprise): The Joint Enterprise is an Ames-unique mechanism developed to combine resources from government, university, and industry to attain objectives in research, development, and technology transfer. The Joint Enterprise uses a consortium approach to involve industry from the onset to develop commercially applicable projects. Using a university or nonprofit organization to broker NASA and industry interests, the Joint Enterprise mechanism establishes all parties' rights and obligations prior to agreement.

Ames University Consortium Program: The University Consortium is another Ames-unique mechanism that allows university faculty and students to work with Ames scientists and engineers on short-term, novel research projects. Special agreements provide for reciprocal use of services, personnel, equipment, and facilities between Ames and the 136 distinguished member universities.

3.3 IMPACT ON CURRENT PROGRAMS

Because of the unique collaborative agreement mechanisms indicated above, Ames has established significant leverage of its research program efforts through industry and university participation.

For example, during FY87 the ARC University Affairs Office awarded approximately $26.8M to support 526 separate grants and cooperative agreements and approximately $3.4M was spent to support 220 active university grants and consortium agreements.

The anticipated scope of the outside component of the proposed Pathfinder efforts is within the capability of the current supporting contracting and grant structure at Ames, with the proviso that a percentage of additional in-house technical expertise be made available to monitor these activities.

4.0 FACILITIES PLANS

4.1 OVERVIEW

This section contains a brief description of all NASA facilities foreseen to play a role in the Pathfinder EVA/Suit Project. The Ames Research Center facilities are described in Section 4.2. Both the existing and planned capabilities of the centers are addressed to the extent possible.

There also exist highly-specialized, well-equipped facilities at other NASA centers which will complement Ames' resident facilities. These facilities will be described in Section 4.3.

In this Plan, the Ames facilities have been divided into two general classes: (1) laboratories and advanced computing capabilities, and (2) simulation and testing facilities. Laboratories and the advanced computing facilities will support the development of innovative concepts and the underlying knowledge necessary to achievement of the Pathfinder technology objectives. The simulation and testing facilities (i.e., technology testbeds) will be used to validate the scientific knowledge and provide convincing, risk-reducing simulations of the innovative Pathfinder technology components and systems.

4.2 AMES RESEARCH CENTER

The Ames Research Center consists of two installations, referred to as Ames-Moffett and Ames-Dryden. Ames-Moffett, which will provide the bulk of research capabilities to support the Pathfinder Program, is located in the heart of "Silicon Valley" at the southern end of San Francisco Bay on 422 acres of land adjacent to the U.S. Naval Air Station, Moffett Field, California. About 2,000 civil service employees and an equivalent number of contractor employees are employed at ARC. Total capital investment at the two ARC locations was $817 million in May 1984. The estimated replacement value of the installation is $2.1 billion.

A number of unique facilities exist at ARC that will provide direct support to the Center's Pathfinder contributions in the EVA/Suit area. In addition to the existing facilities, new capabilities in construction or in planning will add significant potential for the development and validation of Pathfinder technology. A major goal of the ARC Pathfinder activity is the systematic improvement in the facility base (and the technology infrastructure) to support the Agency's future long duration space missions. Brief descriptions of the planned developments which will support the EVA/Suit technologies are contained herein.

4.2.1 Laboratories and Computing Capabilities

Resident facilities will be described in terms of three distinct capability "clusters" which correspond to the major research areas in the EVA/Suit Project:

Life Sciences Laboratories: supporting life sciences, biomedicine, and basic life support research and technology

Human and Intelligent Systems Laboratories: supporting human performance research, automation and robotics, and EVA research and technology development

Advanced Computation Facilities: supporting studies of computational fluid dynamics, computational chemistry, computational vision and intelligent sensing, computational human engineering, and life support component and system modeling and analysis

LIFE SCIENCES LABORATORIES:

Several facilities are concerned with the determination of human physiological and psychological response to simulated space flight conditions. Inasmuch as the research contained in these facilities may influence mission requirements, scenarios, or guidelines, they are described briefly here as sources of indirect input to the EVA/Suit Project.

Human Research Facility: The Human Research Facility (HRF) was designed specifically for studies of the physiological and psychological responses of humans to weightlessness and confinement. It includes test equipment such as lower body negative pressure, exercise ergometry, and a laboratory for bio-chemical analysis.

Psychophysiology Laboratory: The Psychophysiology Laboratory is used for basic research into the use of bio-feedback to counteract undesirable effects of space flight, such as motion sickness, through learned control of cardiovascular and other bodily functions.

12' Radius Animal Centrifuge: The 12-Foot Radius Centrifuge is being used to study the effects of moderate hyper-g intensities (up to 3-g) on the reproduction, growth and development of laboratory sized mammalian animals (mice, rats, guinea pigs). Structural and functional systems of the exposed animals are being delineated which are g-intensity responsive and quantifiable relationships are being established. These relationships are being used to develop various hypotheses on the effects of both fractional-g (less than 1-g) and micro-g through extrapolations of hyper-g results.

Man-Carrying Rotation Device: The Man-Carrying Rotation Device is used to assess the physiological effects of motion on human subjects and their ability to perform various tasks when subjected to precise angular accelerations and rates for specified periods of time. Yaw, pitch, or roll may be imposed by varying the orientation of the subject.

Exercise Physiology Laboratory: The Exercise Physiology laboratory is used for basic and applied research in human physiology to study thermal regulation, exercise training regimens, human aerobic and anaerobic work capacities, fluid-electrolyte physiology, and to measure various cardiorespiratory variables during bed rest and water immersion deconditioning. These studies are directed toward the solution of present and potential space flight crew physiological problems. The laboratory is equipped with a treadmill, isotonic cycle ergometers, isokinetic exercise ergometers, oxygen uptake analyzers, and thermoregulatory instruments with computer interface.

Advanced Life Support Laboratory: The Advanced Life Support Laboratory is involved in studies directed toward the integration of Controlled Ecological Life Support Systems (CELSS) with state-of-the-art physical/chemical support subsystems. Such bioregenerative systems will be designed to sustain crews through anticipated extended duration space flight missions. A major tool in these studies is a closed plant growth chamber used to characterize conditions of growth, food production, atmospheric gas production and use (oxygen and CO_2 respectively), and material recycling. Methods are being developed for efficiently processing human and plant metabolic wastes in parallel, transforming organic carbon, nitrogen, and minerals into forms available to the crew and plant growth. A Science Verification Facility will describe a bioregenerative system combining these elements through test regimes of material recycling and defined closure. Results will contribute to the design of a Human-Rated Test Facility.

20-g Human Centrifuge: The 20-g Human Centrifuge is the only human-rated centrifuge in NASA. Investigators use it to examine the effects of altered gravitational forces on biological systems and instrument packages in order to determine their qualification for flight. The centrifuge has a double-ended arm construction with cabs at both ends. The arm radius to the center of the cab is 25 feet. The test cab size is 6' x 7' x 8' with a maximum payload at each end of 1,200 lb or 16,000 g-lb. Additional equipment weighting up to 2,000 lb can be mounted within four feet of the center of rotation.

HUMANS AND INTELLIGENT SYSTEMS LABORATORIES:

Human Performance Research Laboratory (HPRL): The Human Performance Research Laboratory is a new facility which is under construction at Ames and whose purpose is to support research and technology aimed at improving the human factors of aerospace systems. The two story building, which encompasses approximately 65,000 square feet, will contain offices and state-of-the-art laboratories for approximately 180 scientists, engineers, and supporting technical and administrative staff of the Ames Aerospace Human Factors Research Division, and an 80' by 150' (12,000 square feet) high bay area. The latter is intended to house a testbed for human-interactive systems such as EVA/suit and be used for validation of autonomous systems technologies such as knowledge-based systems for Space Station. Initially, the high bay will be shared between ARC's Aerospace Human Factors Research and Information Sciences Divisions. Eventually, other organizations (e.g., those developing advanced closed-loop life support systems) may also share in the use of the HPRL high bay testbed complex.

Laboratories in the HPRL will accommodate a variety of basic and applied studies of human performance and the interaction of humans with complex machines. The Aerospace Human Factors Research Division also maintains an interactive computing capability consisting of workstations and medium sized mainframe computers of the VAX class, as well as high speed communication channels to the super computers of the Ames Central Computing Facility and the Numerical Aerodynamic Simulation complex. Individual laboratories within the HPRL will support cognitive, perceptual, and social scientists, and scientists and engineers working on advanced aeronautical and space automation and other equipment designed to improve the safety and productivity of space missions, such as advanced space suits and portable life support systems. A local capability to do prototype mechanical and electronic fabrication will also be provided to support the scientific and technical work of the Aerospace Human Factors Research Division.

Virtual Interactive Environment Workstation Laboratory (VIEWS): VIEWS consists of a wide-angle stereoscopic display unit, glove-like devices for multiple degree-of-freedom tactile input, connected speech recognition technology, gesture tracking devices, and computer graphic and video image generation equipment. Head motion of the user is tracked by a helmet-mounted sensor and the derived position and orientation data is used to update the displayed stereo images in response to the users activity. As a result the displayed imagery appears to completely surround the user in 3-D space and contains full motion parallax, motion perspective and binocular parallax information. To interact with the displayed three dimensional environment, the user wears lightweight glove-like devices that transmit data-records of arm, hand and finger shape and position to a host computer. In coordination with connected speech recognition technology, this information is used to effect indicated gestures in the synthesized or remote environment. Current applications of voice and gesture mediated interaction are the control of robotic arms and end-effectors, and associated control of auxiliary camera positions. Similarly, in the virtual data management environment, multiple windows of information and simulated control panels are positioned, sized and activated in 3-D space.

Automation Sciences SADP Brassboard Integration Laboratory: The Systems Autonomy Demonstration Project (SADP) Brassboard Integration Laboratory is used to develop, integrate, and validate knowledge-based systems technology that will thereafter be demonstrated on Space Station testbeds at other NASA Centers. It provides a realistic operating environment to test Expert Systems and other knowledge-based systems technology used in a control, rather than advisory, application.

ADVANCED COMPUTATION FACILITIES:

Numerical Aerodynamic Simulation Facility (NAS): The Numerical Aerodynamic Simulation (NAS) Program provides a national computational capability, in part to act as a pathfinder in advanced large-scale computer system capability; and to provide a strong research tool for NASA, particularly the Office of Aeronautics and Space Technology. It currently has installed two Cray 2s, an ETA 10Q, two Amdahl 5880's managing 181 gigabytes of Mass Storage, and several VAXs. User access to this system is via the NAS Support Processing Network (NSPN) from Silicon Graphics Workstations. Also supported are several external networks, in particular NASNET which provides access to the NPSN for remotely located users, as well as MILNET, CNS, and BARRNET. The operating system of choice is UNIX in all areas. The Program will take delivery of a Cray Y-MP in early fall of 1988 which will further enhance its mission of providing leading edge facilities to the research community. In its pathfinding role, the NAS Program also provides special mini-supercomputers (Alliant, Convex), and special architectures systems (Connection Machine-2), as well as an aggressive program in Advanced Algorithms and Architectures. Through this computational capability and research program, the NAS Program is influencing developments in the computer industry as well as setting future directions for applied computational science.

Ames Central Computing Facility (CCF): There are two supercomputers presently installed at Ames Research Center , managed by the Central Computer Facility. These are a CRAY X-MP/48 and a CRAY X-MP/14se. The Central Computer Facility plans an upgrade to these systems in FY89 which will enhance the state-of-the-art supercomputing capabilities supporting the computationally-intensive mission of the Center. Supporting this complex is a user environment which enhances and reinforces the creativity and productivity of the research community. This environment is being strengthened with the planned acquisition of families of workstations and mid-range systems. These systems will be available for delivery by January 1989, and will be integrated into the existing complex. Also available for use by the research community is a centralized Storage Facility which provides in excess of 100 gigabytes of storage to users of the CRAYs and potential to users of interactive systems. All of these capabilities are integrated into a Center-wide network providing access to all facilities to all users, if required.

Advanced Interactive Workstations: Key to enhancing many of the research programs at Ames and improving their productivity is the use of Advanced Workstations. These workstations have blended together significant computational power, as well as a substantial level of graphics performance to enhance the visualization of engineering and scientific phenomena. In the past few years, workstations have gone from "geometry transformation engines" to integrated computational platforms which can be used to solve a wide range of scientific problems. The overwhelming growth in technology has made it possible for almost every researcher in an organization to have a powerful workstation on his/her desk and the scientists are no longer limited by the time lags associated with existing computational resources. At ARC this has been exemplified by the fast growth in the number of workstations being utilized in scientific research. Currently at ARC there are in excess of 60 Silicon Graphics IRIS Superworkstations in use, as well as numerous lower performance, yet powerful, engineering workstations. Three of the newly released state-of-the-art Graphics Supercomputers from Stellar and Ardent are expected to arrive soon. The significant contribution of these systems which integrate major computational power with instantaneous display of results is that they have increased the ability of the researcher to pursue real time problem improvements. These tools will continue to enhance the researchers' overall productivity, stimulate innovation, and may contribute to new and creative solutions which would have been difficult to envision otherwise. Future technology will pave the way for a human-in-the-loop problem solving approach which is perhaps the more natural method of solving difficult scientific problems. It offers the highest potential for progress and breakthroughs in a wide range of scientific and engineering disciplines.

4.2.2 Simulation and Testing Facilities

Neutral Buoyancy Test Facility (NBTF): The Neutral Buoyancy Test Facility (NBTF) provides simulation of a weightless environment through underwater testing for development and evaluation of space suits, related equipment and procedures for use on space flight. The NBTF has been used for preliminary evaluation of the AX-5 space suit and is ideally configured for evaluation of zero-g related hardware. The NBTF consists of the following systems: a wet tank, 9' deep and 11' in diameter, filled with approximately 5000 gallons of deionized water; an Environmental Control System (ECS) which provides the space suit with a breathable air supply and a thermal control system for comfort; a communication system, providing two-way communications between the suited-subject and test personnel; and an overhead pneumatic hoist, used for wet tank ingress and egress by the suited-subject. Four personnel conduct NBTF test operations. They are a test director, who directs the test and controls the ECS for the subject, a hoist operator, and two safety divers.

Plans for a new NBTF are underway. It will be constructed adjacent to the HPRL. The new facility will consist of a wet tank, 9' deep and 25' in diameter; an Environmental Control System for breathing air and thermal regulation of the suited-subject; a communication system; and an ingress/egress mechanism. In short, the new facility will retain all of the capabilities of the present facility. However, the larger size of the tank will permit a greater degree of translation for the suited-subject than in the current NBTF without incurring the increased bends risks and high operational overhead penalties associated with tanks of greater depth. The greater diameter will also allow for more precise range of motion measurements using state-of-the-art motion analysis systems.

4.3 OTHER NASA CENTERS

ARC resident facilities are complemented by the highly specialized facilities at other NASA centers.

4.3.1 Johnson Space Center

The Johnson Space Center (JSC) has played a major role in the development and testing of flight hardware for EVA since the Gemini program. The stringent test requirements for flight qualification and the astronaut presence at JSC have lead to the construction of some very specialized laboratories and test facilities. These facilities will be used in the development of Pathfinder EVA/suit technology, in addition to their test and training roles for ongoing programs. The facilities are described below.

Weightless Environment Test Facility (WETF): The WETF is housed in Building 29 and is under the supervision of the Man-Systems Division. Like the NBTF at Ames, it provides simulation of a weightless environment through underwater testing and is used in the evaluation of space suits and other EVA equipment. The facility consists of an in-ground tank 78' x 33' x 25' deep, holding approximately 500,000 gallons of heated water, with associated water filtration/chlorination system. An environmental control system (ECS) is able to supply thermal regulation and breathing air for a maximum of three suited-subjects. An overhead hoist is used for ingress and egress of suited-subjects from the tank and a 2-way communication system is in place for communication among the subjects and test personnel. Test personnel include: a test director, an ECS operator, a topside monitor, a hoist operator, a safety officer, television crew, suit technicians, suit engineer(s), medical personnel, and the test conductor. The number of safety and utility divers is dependent on the test duration and the number of suited-subjects; backup diver(s) are also present. Also within Building 29 are offices for technicians, engineers, the facility manager, the test director, the supervisor, and secretarial support, as well as storage for support equipment. Numerous mockups have been made for use in the WETF, for evaluation of past and current space hardware configurations, including a full size mock-up of the Shuttle payload bay.

KC-135: One KC-135 Airplane, tail # NASA930, is housed at Ellington AFB, about 6 miles from the Space Center.The plane is flown in parabolas which provide 20-25 seconds of weightlessness (zero-g). The flight parabolas can be varied to provide a partial-g environment. Approximately 40 parabolas are flown on a typical mission. The flights have been used for astronaut orientation to zero-g, as well as in space life sciences research and engineering development. EVA-related tasks performed in the KC-135 to date include the biomechanical evaluation of suit mobility with the Cybex dynamometer and suit don/doff. In addition, the KC-135 capabilities have been used by members of the international space community.

Anthropometry and Biomechanics Laboratory: The Anthropometry and Biomechanics Laboratory is located in Building 29 and covers 1,600 square feet. The primary functions of the lab are the determination of astronaut size and reach envelopes to be used in space vehicle design, and the determination of astronaut musculoskeletal strength, power, and endurance. Investigation of 1-g biomechanics are performed and protocols outlined for associated zero-g simulations. It contains an environmental control system for supporting 1-g suited tests in which an overhead suspension system is used to reduce the effective weight of the suit on the subject. The lab has close ties with the Graphics Analysis Facility at JSC which can provide computer drawings and animations of the biomechanics and anthropometry of the suited crewmembers. One-g investigations are done in conjunction with both WETF and KC-135 investigations; co-location of this lab with the WETF in Building 29 facilitates such cooperation. The facility is equipped with a PDP-11/44 data acquisition/reduction system with 32 channel capability and associated terminals and printers; a force/torque sensor; a force plate, waterproof to 60 feet; two Cybex dynamometers; and electromyographic equipment. The electromyography system is being upgraded with telemetry equipment, and procurement is underway on a 3-D video motion tracking system with high speed capability.

The facility is currently staffed by one principal investigator, 3.5 permanent contractors, and 2 co-op students. Additional support is provided by Lockheed to meet project requirements. Staffing will be increased at an approximate rate of one man-year/year, over the next five years.

Human-Computer Interaction Laboratory: The Human-Computer Interaction Laboratory is located in Building 17. Its primary purpose is to conduct experiments and develop models of human interaction with or processing of computer mediated information. It is equipped with a network of microcomputers and a MicroVax II, plus tools and equipment for generating and presenting displays, evaluating input devices and techniques, and collecting and analyzing user performance data for various displays and controls in 1-g and in parabolic flight. The Laboratory performs evaluations of conceptual designs and conducts research for display content and format, control type, use of text and graphics, and workstation design.

Lighting Laboratory: The Lighting Laboratory performs analyses of factors relevant to the astronaut's visual environment. Special equipment is employed to assess ambient and special lighting needs, reflective and transmissive characteristics of materials, and IVA/EVA operations lights. The Laboratory defines requirements and evaluates design concepts for lights, visual displays, alignment aids, docking targets, etc., for on-going programs. The Laboratory also performs research to take advantage of new technologies applicable to the visual environment.

Crew and Thermal Systems Test Chambers: These are four environmental chambers housed in Buildings 7 and 32.

The first of these is the 8-Foot Chamber. It is 8' in diameter and approximately 14' long, with a horizontal axis. It is used primarily in the parametric evaluation of portable life support systems. The "can man" provides control of simulated metabolic processes such as CO_2 production, O_2 consumption, heat production, and humidity level to evaluate PLSS subsystems.

The 11-Foot Chamber is a man-rated suit test facility in which suits are metabolically loaded. It is approximately 19' long, with the entrance and two successive "locks" at one end. The innerlock houses the suited-subject, while the outerlock is held at an intermediate altitude to contain rescue observers. The chamber is equipped with total life support systems for the subjects (up to two), treadmills, and a weight release system. Currently it is used to train the Shuttle crew, using EVA mission simulations. A thermal vacuum space suit gloves test chamber is attached to the outerlock.

Chamber B is used for thermal vacuum qualification of space hardware with vacuum pumping capability to 10^{-6} torr and liquid nitrogen cold walls. It has a 25' diameter and is 26' in height. As in the 11-Foot Chamber, there are two man locks, side-by-side, one containing a rescue crew at intermediate altitude, and one used as the crewman's airlock. Two rolling bridge cranes with 50-ton capacity are used to remove the chamber top and insert large test articles. A modular solar simulator array (with xenon lamp sources) mounted on the top head facilitates changes in location and beam size to accommodate test requirements. Solar incident angles other than vertical can be achieved by installing mirrors in the chamber. Infrared sources are available to simulate albedo and planetary radiation.

Chamber A, the largest of the chambers with a 55' diameter and a 90' height, is not currently man-rated. It is currently used for unmanned testing of space hardware. Test articles are inserted by means of overhead cranes. Two 50-ton cranes are outside the chamber and four independently operated 25-ton cranes, lowered through removable sections of the top head, are used inside the chamber. This chamber also has dual manlocks which can be sued as independant altitude chambers when the inner door is bolted. The chamber has LN_2 cold walls and can provide simulated albedo and planetary radiation.

In addition, several smaller chambers (Chambers D-G, I, N, P, T-V, X), varying in size from 0.4 m diameter to 1.8 m diameter, are available for smaller test articles.

4.3.2 George C. Marshall Space Flight Center

Neutral Buoyancy Simulator (NBS): The NBS at the Marshall Space Flight Center (MSFC) consists of a cylindrical tank, 75' in diameter and 40' deep, containing 1.3 million gallons of chlorinated, filtered, heated water. Like ARC's NBTF and JSC's WETF, it is used for simulation of the weightless environment in the evaluation of space suits and related EVA equipment for zero-g missions. An overhead floating hoist system with 2,000 lbs. capability is used for suited-subject tank ingress and egress. The environment control system can supply up to four suited-subjects with breathing air and thermal regulation. A typical test operation is staffed with up to 20 people: two divers per suited-subject, hoist operator, ECS operator, test director, medical personnel, suit technician(s), and various support personnel, such as video crew and photographers. The Shuttle cargo bay has been constructed as a full-size mockup for use in the NBS, as have other elements of the Space Station.

4.3.3 Langley Research Center

Langley Research Center (LaRC) has been designated the lead center for Automated Space Construction in the Pathfinder Project. One existing and one planned facility are foreseen as support test facilities for the ARC EVA/Suit Project.

Solar Light Simulator: The Solar Light Simulator is an ambient light simulation system used for aeronautics R&T. It consists of an integrating light elliptical cab surrounding a cockpit simulator. Studio TV lights and a solar source provide the light sources, and can be used in combination with reflectors, i.e. to direct the sun at the display panel. Both the direction and color of the lights are under computer control. The simulator can reproduce the cockpit ambient light environment, from sunrise to dusk. In its current configuration, the facility is usually operated with one engineer in addition to the primary operator and the test subject. With modification, the facility will be capable of simulating the ambient light environment on a planetary surface.

Automated Construction Testbed: The Automated Construction Testbed is a facility in planning at LaRC. It will provide a means to evaluate and develop telerobotic systems and operational procedures for in-space assembly and construction, prior to in-space operations. The capability will evolve to allow testing of a wide range of space structure concepts including utilities and facets installation, high capacity joints and assembly, and service and repair of platforms and vehicles. The facility will incorporate mobility for the robotic manipulator, and will be sufficiently flexible to accommodate other construction concepts (i.e. space cranes, berthing/joining of larger modules). In addition, it will support system integration and coordination of several manipulators, such as multiple arms and the operator interface to automated construction tools. This facility may be used to clearly define the role of EVA in space construction and evaluate the EVA interface to automation technology.

4.4 FACILITIES ASSESSMENT

Existing and planned ARC resident facilities, combined with the specialized facilities of JSC, LaRC, and MSFC, are adequate for developing and testing the base technologies, in the form of components and subsystems, with one exception. Test requirements and facilities have not been defined for evaluation of hardware under conditions of partial-g (1/3-g, 1/6-g). Test requirements will evolve from mission requirements definition (WBS 1.1.1).

In the latter half of the ten-year Pathfinder Program, efforts will concentrate on the integration of components and subsystems into subassemblies and larger systems. There is a need for the development of an Integrated Systems Testbed (ISTB) in which such integrated systems will be tested for satisfactory performance in the simulated mission environment. The integrated systems test requirements for EVA hardware will be defined in WBS 1.1.3.4, using information produced in WBS 1.1.1 and 1.1.2, Mission Requirements Definition and Human Requirement Definition, respectively.

The facilities of NASA and other federal agencies will be used to the fullest extent. Facilities of Pathfinder program university grantees and sub-contractors will also be utilized where possible. Only where existing facilities are inadequate and cannot be economically upgraded to meet the test requirements, will the construction of a new facility be considered.

5.0 IN-SPACE RESEARCH AND TECHNOLOGY

In contrast to the requirements for vehicular life-support systems which will operate for long periods of time in a zero-g environment, EVA PLSS and suit systems have a limited need for flight testing. The main reasoning behind this statement is that new EVA PLSS and suit systems will primarily operate in partial-g environments on both the Lunar (1/6-g) and Martian (1/3-g) surfaces. Exceptions to this may occur if Pathfinder mission scenarios include landings on Martian moons where the gravity level is .001-g. All aspects of the integrated EVA system intended for use on the Phobos or Deimos surfaces must be tested as part of the flight qualification procedure.

6.0 TECHNOLOGY TRANSFER PLANNING

6.1 OVERVIEW

The broad technical challenges, limited resources, and multi-center aspect of the EVA/Suit Project, and of the Pathfinder Program in general, demand that effective technology transfer mechanisms be developed from the beginning of the program and that a concerted effort be maintained to ensure that these mechanisms achieve the desired result. The ARC EVA/Suit Project Manager will coordinate research efforts with the Inter-Center Working Groups, where they have been established. Further direct collaboration with development or mission lead centers will be established to ensure a close tie between the research activities and the requirements of the project so that the ultimate tranfer of technology to flight development centers such as JSC will be effective and cost-efficient.

6.2 INTER-CENTER RELATIONSHIPS

Ames Research Center is the designated lead center and is responsible for project planning and implementation, coordination of the technical interfaces among supporting elements of the project, and implementation of the R&T effort.

Research and development efforts at the task level will be managed and/or performed by staff at LaRC and JSC as well as at ARC, and at supporting contractors' and university facilities. Coordinated effort among the centers is mandatory since it is economical and provides an improved resource base (personnel and facilities) to accomplish the effort. The opportunities for such coordination will be made apparent to researchers at all centers by the EVA Manager at the centers, who will maintain regular communications among themselves and with the ARC Project Manager. The formal procedure for the planning, monitoring, and reporting of task efforts is outlined in the Management Section of this document (Section 2.2).

6.3 RELATIONSHIPS TO R&T BASE

The FY89 OAST (Code RC) budget for EVA R&T is $636K. These funds are directed toward the development of generic EVA technology. More specifically, FY89 R&T tasks will be funded in the following areas:

- fusible materials research
- atmosphere control analytical studies
- CO_2 control systems technology
- PLSS automatic control technology
- display human factors requirements
- pressure suit materials and structures
- gloves and end-effectors

An assessment of the relationship between this R&T base program and the Pathfinder elements has been conducted to use as basis to ensure technology transfer between these project elements and to avoid duplication of effort. A reassessment will be conducted annually, concurrently with the Project Plan updating.

6.4 TECHNOLOGY DEMONSTRATION

Where appropriate, ARC will use testbeds or technology development demonstration capabilities for proof-of-concept demonstrations to bring the technology to a level of maturity appropriate for transferring to a development enter. Development centers and the Astronaut Office will be encouraged to participate in these demonstrations to foster teaming and to develop confidence in the technology developed. These testbeds will be research and technology development oriented in nature and will not duplicate, or otherwise compete with, higher fidelity systems integration, engineering, or operations oriented testbeds which may be developed at the development centers. As research facilities, however, they may be made available to other centers as well as to industry and universities in support of related technology development requirements.

6.5 INDUSTRY RELATIONSHIP

6.5.1 Overview

An important component of the nation's civilian space R&T capability resides in industry. At present, unlike its relationship with the aircraft industries, NASA is a net customer (rather than provider) of space technology. Development of NASA in-house expertise under this Pathfinder project is expected to change the relationship. Further, industry participation in actual flight mission development and integration is essential. Therefore, transfer of NASA developed technology is vitally important. It will enhance and complement the industry technology base which will add to the nation's overall space capability and will ultimately feed back into NASA programs.

Both existing and planned facilities of the three currently involved centers (ARC, JSC, and LaRC) which are foreseen to have application to the Pathfinder EVA/Suit Project are described in the Facilities Section of this document (Section 4.0).

6.5.2 Industry Teaming

A concerted effort will be made to involve industry in the EVA/Suit activities via contracts, collaborative agreements, and other teaming relationships. Space facilities and technology development testbeds will also be made available for industry use in the same way that aeronautical facilities are made available to the aeronautics community.

6.5.3 Industry IR&D

Industry IR&D represents an important national space investment. EVA Managers will be encouraged to seek opportunities to review and influence the direction of related IR&D technologies which have direct applications to their activities. This will serve to increase the leverage of technology investments in these areas and identify potential areas of future collaboration as well as avoid unnecessary duplication of effort.